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Assessing the macroeconomic impact of alternative macroprudential policies☆

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ABSTRACT

This article assesses effects on the wider economy and overall costs and benefits of two alternative macroprudential policies - loan-to-value ratios on mortgage lending and variable bank capital adequacy targets. It also traces the potential effects of such policies if introduced prior to the subprime crisis. The work is performed within the National Institute Global Econometric Model, with a focus on Germany, Italy and the UK. Detailed banking sectors and addition of a macroprudential block to our model enable effects of policies to be captured. A systemic risk index tracks the likelihood of the occurrence of a banking crisis and establishes thresholds at which macroprudential policies should be activated by the authorities. Capital adequacy impacts the economy by acting on the spread between borrowing and lending of corporates and households, while loan-to-value transmits through its impact on the housing market. We find generally loan-to-value policy has a lesser effect than capital adequacy on crisis probabilities and net benefits, but there is considerable cross country variation. We show that the introduction of macroprudential policy prior to the crisis would have led to improvement in a number of key macroeconomic measures and might thus have reduced the incidence of the crisis.

1. Introduction

Since the global financial crisis, there has been widespread adoption of macroprudential policies in both advanced and developing countries. Macroprudential policy can be defined as being focused on the financial system as a whole, with a view to limiting macroeconomic costs from financial distress (Crockett, 2000), and with risk taken as endogenous to the behaviour of the financial system. However, as noted by Galati and Moessner (2014, p2), “analysis is still needed about the appropriate macroprudential tools, their transmission mechanism and their effects”. A primary instrument for macroprudential policy has not yet emerged. For authorities, triggers for introducing macroprudential policy are typically house prices, credit and the credit-to-GDP gap or judgemental assessments based on a range of macroprudential indicators. Theoretical models are in their infancy and empirical evidence on the effects of macroprudential tools is still scarce.

In this context, we suggest that while extant macromodel-based work can highlight the transmission mechanism of real and financial factors, and model calibrations can help with understanding how macroprudential regulation can reduce the risk of crisis, they often omit feedback from the macroeconomy to the financial sector, in particular a macroprudential reaction function. Additionally, they are often calibrated rather than estimated and/or would find disequilibrium hard to manage. Although recent empirical studies[1] do show promising results for the effectiveness of macroprudential policies, they are generally limited to assessing effects on a single variable, which is typically house prices or credit. Thus, in each case a full and accurate picture of the economy-wide impact of macroprudential policy fails to emerge.

We contend that an assessment of the comparative macroeconomic effects of macroprudential policies can be most appropriately addressed

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[1] See for example Kuttner and Shim (2016), Cerutti et al. (2017), Carreras et al. (2016, 2018a) and their references.

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in the National Institute Global Econometric Model, NiGEM.[2] It is more flexible and versatile and potentially more accurate that existing theoretical tools, while enabling economy-wide effects and interactions to be captured, unlike single-variable empirical work. Accordingly, in this paper we introduce macroprudential considerations to NiGEM, and show outcomes of simulations, focusing on country models for the UK, Germany and Italy.[3] Our chosen macroprudential instruments are variable bank capital adequacy and mortgage loan-to-value ratios, which the studies, cited in footnote 1, have shown to be particularly effective. The former impacts the economy by acting on the spread between borrowing and lending of corporates and households, while the latter transmits through its impact on the housing market.

A key innovation in this paper is that a systemic risk index keeps track of the likelihood that a financial crisis takes place. This develops from the literature on early warning models for banking crises as a complementary target for macroprudential policy (see for example Demirgüç-Kunt and Detragiache (2005), Davis and Karim (2008) and Barrell et al. (2010a)). The index is a function of early warning indicators derived from Barrell et al. (2010b) and Karim et al. (2013), namely banking sector capital adequacy and liquidity ratios, house price growth and the current account to GDP ratio. There is scope to trigger macroprudential policy directly or enable policy to be triggered endogenously as the systemic risk indicator reaches critical levels, which can itself vary between countries or be set separately.

The paper is structured as follows; in Section 2, we present a brief taxonomy of macroprudential tools. In Section 3, we review some of the extant theoretical work on macroprudential policy in the macroeconomy. Section 4 introduces NiGEM and Section 5 looks at some earlier work on macroprudential policy in NiGEM. Section 6 outlines the specific extensions to NiGEM that we are introducing and Section 7 shows the key variables in the systemic risk function. Section 8 shows the results of three simulations using the macroprudential sector, showing the comparative macroeconomic impact of the alternative macroprudential policy, and including an assessment of the effect of introduction of such policies prior to the subprime crisis. Section 9 considers costs and benefits of different macroprudential policies and Section 10 concludes.

2. Taxonomies of macroprudential tools

Authorities around the world are implementing a macroprudential pillar to economic policy, to complement microprudential, monetary and fiscal policy. Such a pillar is aimed at preventing financial crises by limiting systemic risk – the danger that there arises widespread disruption to provision of financial services, that impact in turn on the real economy. In order to appropriately calibrate such policies, there is a clear need for a forecasting and simulation tool to assess appropriate triggers for macroprudential intervention, the wider macroeconomic effect of alternative interventions and their relationship to monetary and fiscal tools. Such a tool should also allow for global interactions and trends in financial and economic quantities and prices and cross border spillovers. NiGEM, extended to allow for user-driven as well as endogenous macroprudential interventions, is ideally suited to such a role.

Macroprudential policy may be varied across time, where the policy seeks to limit the procyclical build-up of risk during a credit-driven upturn (the "time dimension"). Alternatively, it may be implemented at the cross-sectional level, whereby the aim is to maximise the resilience of the financial system to shocks arising from failure of large institutions or markets (the "cross-sectional dimension"). Table 1 (derived from Bennani et al., 2014) shows there are tools that focus on addressing the time dimension (procyclicality) versus the cross-sectional dimension, within which there are tools to target capital, assets and liquidity, as shown below. The current focus is on tools in the time dimension shown in bold.

Table 2 (from Claessens et al. (2014)) shows how some tools are used to dampen the expansionary phase while others target the contractionary phase. Others again focus on contagion between systemic institutions and they aim to control risk via capital, assets or liquidity. Our own approach focuses on tools to dampen the expansion (marked in bold in Table 2), although the contagion elements would also be reflected in any impact of such policy on aggregate actual or target capital adequacy.

General versus specific is another taxonomy of macroprudential tools. General macroprudential instruments are notably capital or provisions held by institutions (either in time series or cross-section) not specific to sectors they lend to. An example is the Basel III countercyclical buffer of up to 2.5 percentage points for banks, which should be raised when times are good and lowered when they are bad, and which we employ in our own work. Dynamic provisioning across bank balance sheets as in Spain also fits into this category. These are tools specifically developed to mitigate systemic risk. There are additional tools that may be relevant at times such as reserve requirements, liquidity regulations, capital controls and limits on system-wide currency mismatches.

There are also specific tools targeted to sectors such as housing. These were often not originally developed with systemic risk in mind, but can be modified to target systemic risk. Macroprudential surveillance focused on house prices as a key indicator is common across many countries. Whereas attempts to regulate house purchase lending were historically less widespread in advanced countries, it is becoming more common in the light of the sub-prime crisis (CGFS (2010); Darbar and Wu (2015); Kuttner and Shim (2016)). Examples of such tools are the loan-to-value ratio which we shall use in our own work, debt-service to income, housing-related taxes, limits on exposure to housing, risk weights on housing loans and loan-loss provisioning requirements linked to housing loans. A further breakdown in specific tools is between supply-side credit policies (limits on exposure to housing, risk weights on housing loans and loan loss provisioning requirements linked to housing loans), demand-side credit policies (loan-to-value ratio and debt-service to income ratio) and housing-related tax policies that affect house prices directly (see Kuttner and Shim, 2016).

In this context, according to empirical work (as summarised and extended in Carreras et al. (2016; 2018a)), effective tools of macroprudential policy include loan-to-value ratios and bank capital requirements as well as debt-to-income limits and taxes on financial institutions. We have scope, as discussed below, for implementing loan-to-value and capital requirements in NiGEM.

Table 1
The time and cross-sectional dimensions.

	Time dimension	Cross-sectional dimension
Capital	**Countercyclical capital buffer**	
	Dynamic provisioning	G-SII and O-SII buffer
	Sectoral capital weights	Systemic risk buffer (SRB)
	Countercyclical leverage ratio	Leverage ratio
Assets	**Loan-to-value (LTV) caps**	
	Loan-to-income (LTI) caps	Large exposure measures
	Debt-to-income (DTI) caps	Concentration limits
Liquidity	Limits on loan-to-deposit ratio	Systemic liquidity surcharge
	Time varying liquidity ratios	Liquidity coverage ratio (LCR)
	Time varying margin requirements	Net stable funding ratio (NSFR)
		Minimum haircuts/margin floors
		Reserve requirements

Source: Derived from Bennani et al. (2014). Note that not all of these policies have been implemented in practice to date.

[2] The model has a wide range of users among International Organisations, Regulators, Central Banks, Financial Institutions and Research Groups, including Central Banks.

[3] These major EU and G-7 countries have similar overall banking regulation (owing to common membership of the EU) but also show contrasts, for example in financial structure (bank-based in Germany and Italy, market-based in the UK). They also vary in response to the crisis (most severe in the UK, then in Germany and least severe in the Italy) and in bank capital and liquidity (lower in Germany than in Italy and the UK).

Table 2
The phases of the cycle.

	Restrictions related to borrower, instrument or activity	Restrictions on financial sector balance sheets (assets, liabilities)	Capital requirements, provisioning, surcharges	Taxation, levies	Other (including institutional infrastructure)
Expansionary phase	**Time-varying caps/limits/rules on** - DTI, LTI and **LTV** - margins, hair-cuts - lending to sectors - credit growth	Time-varying caps/limits on: - mismatches (FX, interest rate) - Reserve requirements	**Counter-cyclical capital requirement**, leverage restrictions, general (dynamic) provisioning	Levy/tax on specific assets and/or liabilities	Accounting (e.g. varying rules on mark-to-market) Changes to compensation, market discipline, governance
Contractionary phase: fire sales, credit crunch	Adjustments to specific loan-loss provisioning, margins or hair-cuts (e.g. through the cycle, dynamic)	Liquidity limits (e.g. net stable funding ratio, liquidity coverage ratio)	**Counter-cyclical capital requirement**, general (dynamic) provisioning	Levy/tax (e.g. on non-core liabilities)	Standardized products OTC vs on exchange Safety net (Central Bank/Treasury liquidity, fiscal support)
Contagion, or shock propagation from SIFIs or networks	Varying restrictions on asset composition, activities (e.g. Volcker, Vickers)	Institutional specific limits on (bilateral) financial exposures, other balance sheet measures.	Capital surcharges linked to systemic risk	Tax/levy varying by externality (size, network)	Institutional infrastructure (e.g. CCPs) Resolution (living wills) Varying information, disclosure

Enhancing resilience
Dampening the cycle
Dispelling gestation of cycle
Source: Claessens, Ghosh and Mihet (2014)

3. Macroprudential policy in theoretical macroeconomic models

Before introducing NiGEM, we highlight some recent work in the field of macroprudential policy and macroeconomics as background. Galati and Moessner (2014) give a helpful breakdown of progress in macroprudential modelling, into three areas: banking/finance models, three-period banking or Dynamic Stochastic General Equilibrium (DSGE) models, and infinite-horizon general equilibrium models, which we follow in this paper.

Banking/finance models, in the tradition of Diamond and Dybvig (1983) highlight how financial contracts are affected by various incentive problems related to information asymmetry and commitment that can entail default. Then, there can be self-fulfilling equilibria generated by shocks, leading to systemic financial instability. They accordingly seek to explain the interaction of borrowers and lenders. For example, Perotti and Suarez (2011) look at price-based and quantity-based regulation of systemic externalities arising from banks' short term funding. Accordingly, current liquidity regulation could be justified, together with a Pigovian tax on short term funding. However, such models tend to be cross section and omit the time series dimension. They thus cannot be used to address procyclicality. Furthermore, they tend to be partial equilibrium and thus omit key general-equilibrium effects.

Such effects are included in three-period general equilibrium models of the interaction of asset prices and non-financial and financial sector systemic risk. Such models assess risk taking by heterogeneous agents in an economy vulnerable to such systemic risks. For example there may be financial amplification during booms and busts that has external effects, as in Goodhart et al. (2012) and Gersbach and Rochet (2012a and b). Individual agents take decisions without allowing for the general-equilibrium effects of their actions, in particular the effects of asset sales caused by excessive borrowing on asset prices. Accordingly, they generate patterns of feedback loops entailing falling asset prices, financial constraints and fire sales. Then, macroprudential tools can be shown as helpful in preventing fire sales and credit crunches, including loan-to-value ratios, capital requirements, liquidity coverage rations, dynamic loss provisioning and margin limits on repos by shadow banks (Goodhart et al., 2013).

Further results of interest are provided by models that focus on the functions of banks in the economy such as improving liquidity insurance, risk sharing and raising funding. These, as shown by Kashyap et al. (2014) can then be used to analyse weaknesses underlying the global financial crisis, notably excessive risk taking by underfunded banks relying on short-term funding and exploiting the safety net. Horvath and Wagner (2013), meanwhile, show that macroprudential regulations can lead savers and banks to alter other portfolio choices. Countercyclical regulation can worsen cross-sectional risk for example, although tools to reduce cross-sectional risk may reduce procyclicality.

Infinite-horizon DSGE models with financial frictions build on the insights of papers such as Bernanke et al. (1999) on the financial accelerator. Such models (e.g. Goodfriend and McCallum, 2007) were traditionally linear, so found it hard to deal with non-linearities implicit in systemic risk and changes in regulation. They tended to assume complete markets and that defaults either do not occur or are exogenous. And furthermore they tended to ignore endogenous leverage. So a crisis is modelled as a big negative shock that gets amplified rather than a credit boom that gets out of control (Boissay et al., 2013).

More recent models have sought to overcome these problems, with multiple equilibria, non-linearity, externalities and amplification mechanisms being more sophisticated. Hence macroprudential policies can be better assessed, although the models have to remain small due to the difficulty of the solution methods (Galati and Moessner, 2014). Borrowers may, for example, face occasional binding endogenous borrowing constraints in times of crisis as in Fisher's (1933) debt-deflation paradigm. These may in turn be linked to falling asset prices and declining net worth, see for example Benigno et al. (2013).

Meanwhile, models such as Brunnermeier and Sannikov (2014) look at global dynamics in continuous-time models with financial frictions. The financial sector does not internalise the costs associated with excessive risks, so there is high leverage and maturity mismatch. Securitisation allows risk to be offloaded by the financial sector but raises overall risk-taking. The economy has low volatility and adequate growth in steady state, but the steady state is unstable due to large shocks provoking endogenous leverage and risk taking with feedback loops from the financial to the real economy. The model features a pattern of rising leverage and amplification when aggregate risk declines, as in the great moderation prior to the global financial crisis.

Antipa and Matheron (2014) review potential tensions between monetary and macroprudential policies given overlapping impacts. They use a DSGE model calibrated to Euro Area data with a financial friction manifested in a collateral constraint. Macroprudential policy affects this constraint cyclically and the work entails investigation of the zero lower bound (ZLB). Results include the following: macroprudential policies act as a useful complement to monetary policy during crises, by attenuating the decrease in investment and, hence, output; forward guidance is very effective at the ZLB, by providing a substantial boost to demand and reducing the costs of private deleveraging at the same time; overall, countercyclical macroprudential policies do not undo the benefits of forward guidance, but rather sustain them.

Rubio and Carrasco-Gallego (2016) provide a DSGE setting for studying macroprudential policy implementation in a country (Spain) within a monetary union (the Euro area), in interaction with partner countries. They find that a loan-to-value policy is welfare enhancing for the Euro area. If one country does not implement the policy, but the rest of the Euro area does, this country still benefits as a result of its partners' implementation of the policy because it gains from a more stable financial system without incurring any output costs. However, if all Euro countries actively implement the policy, the welfare gains for all of them are larger.

Turdaliev and Zhang (2018) outline a small open-economy DSGE model featuring a banking sector, in which financial frictions are explicitly modelled and there are two types of households. They estimate the model using Canadian data and suggest a macroprudential approach to reducing household indebtedness is most appropriate; this is because monetary policy that reacts to household debt increases inflation volatility and lowers borrowers' welfare. In contrast, using macroprudential policies such as lowering the loan-to-value ratio limit increases borrowers' welfare.

In general, such models highlight the transmission mechanism of real and financial factors, with the combination of macroeconomic boom, credit boom and low interest rates being dangerous, with consumption smoothing and precautionary saving being key underlying factors in financial imbalances' build-up. Model calibrations can help with understanding how macroprudential regulation can reduce the risk of crisis. State contingent taxes can also play a role, as can Pigovian taxes and an optimal mix of macroprudential policy and bailouts However, such models often omit feedback from the macroeconomy to the financial sector, in particular a macroprudential reaction function, are calibrated rather than estimated and/or would find disequilibrium hard to manage. Hence, we contend that for practical policy purposes in macroprudential policy – such as comparing effects of alternative macroprudential policies - a semi-structural global macroeconomic model such as NiGEM is both more flexible and versatile and potentially more accurate that the theoretical tools set out above.

4. The NiGEM model

This section provides a succinct non-technical exposition of the National Institute's Global Econometric Model, NiGEM which we use in our research. Where relevant to the analysis, details of the model are presented in the text to follow, but an in-depth discussion falls beyond the scope of this paper.[4] NiGEM is a global econometric model, and most countries in the EU and the OECD, as well as major emerging markets, are modelled individually. The rest of the world is modelled through a set of regional blocks so that the model is global in scope. All country models contain the determinants of domestic demand, export and import volumes, prices, current accounts and gross foreign assets and liabilities. Output is tied down in the long run by factor inputs and technical progress interacting through production functions. Economies are linked through trade, competitiveness and financial markets and are fully simultaneous.

Agents are presumed to be forward-looking in financial and factor markets, but nominal rigidities slow the process of adjustment to external shocks. The model has complete demand and supply sides and there is an extensive monetary and financial sector, together with household and government sectors. As far as possible, the same theoretical structure has been adopted for each country. As a result, variations in the properties of each country model reflect genuine differences emerging from estimation (which should also capture different institutional features), rather than different theoretical approaches.

Policy reactions are important in the determination of speeds of adjustment. Nominal short-term interest rates are set in relation to a forward looking feedback rule. Long-term interest rates are the forward convolution of future short-term interest rates with an exogenous term premium. An endogenous tax rule ensures that governments remain solvent in the long run; the deficit and debt stock return to sustainable levels after any shock, as is discussed in Blanchard and Fisher (1989). Exchange rates are forward looking and so can 'jump' in response to a shock.

Within NiGEM, labour markets in each country are described by a wage equation (see Barrell and Dury, 2003 for a detailed description) and a labour demand equation (see, for example, Barrell and Pain, 1997). The wage equations depend on productivity and unemployment, and have a degree of rational expectations embedded in them – that is to say the wage bargain is assumed to depend partly on expected future inflation and partly on current inflation. The speed of the wage adjustment is estimated for each country. Wages adjust to bring labour demand in line with labour supply. Employment depends on real producer wages, output and trend productivity, again with speeds of adjustment of employment estimated and varying for each country.

Particularly relevant to our current work is that NiGEM allows the macroeconomy to be affected directly by financial regulation and financial instability. When banks increase the spread between borrowing and lending rates for households, for example due to higher capital requirements, it changes households' incomes, and can also change their decision making on the timing of consumption, with the possibility of inducing sharp short-term reductions. The volumes of deposits and lending that result are demand determined. Changing the spread between borrowing and lending rates for firms may change the user cost of capital and hence investment. This in turn affects the equilibrium level of

[4] For further details, the reader is referred to the NiGEM website: https://nimodel.niesr.ac.uk/. For earlier analysis using NiGEM, in this case to assess the impact of Brexit, see Baker et al. (2016) and Ebell et al. (2016).

output and capital in the economy in a sustained way.

5. Earlier work introducing macroprudential policy in NiGEM

To incorporate macroprudential policy in NiGEM for a project commissioned by Sveriges Riksbank, Davis et al. (2011) undertook a number of modifications of the existing Swedish NiGEM model. First, housing wealth was included in the consumption function; second, household liabilities were allowed to be driven by housing wealth (previously it had been driven by income); and third, the house price equation incorporated an income, wealth and mortgage effect as well as an effect of long real rates and the household sector lending spread (the previous equation had included only the interest rate terms). Hence, the effect of banks on the economy via lending spreads was broadened from fixed investment, the stock of capital and consumption to also include house prices, which affects consumption via housing wealth.

Besides standard simulations, Davis et al. (2011) imposed three macroprudential ones. One was for a three percentage point rise in the bank spread for mortgages only, to show the effect of higher countercyclical capital requirements on mortgages for two years. Subsequently, they applied the same shock to all bank lending so it also affects the spread for the corporate sector, showing the effect of rising general capital requirements for banks. Finally a fall in regulated loan-to-value ratios was proxied by shocking the implicit user cost of housing by three percentage points for two years. The main difference between the bank spread for household lending and the user cost of capital was the effect of the household lending spread on personal income which is absent for the user cost of capital shock.

Evidence from these NiGEM simulations suggested that macroprudential policies, focused on the housing market, can have a distinctive impact on the economy which could helpfully complement monetary policy at most points in the cycle. These results are in turn broadly consistent with work assessing theoretically how macroprudential policies may affect the economy, as cited above.

Accordingly, a generalised rise in capital adequacy affecting all lending had a quite marked impact in GDP, mainly via investment rather than consumption. On the other hand, a more focused capital adequacy rise for mortgage lending only, or a loan-to-value ratio policy, appeared to have scope to reduce credit and house prices and hence consumption with less effect on the rest of the economy than other options. That said, the housing-based policy may of course be more subject than capital-adequacy based policies to disintermediation. Capital adequacy for mortgage lending affects GDP more than the loan-to-value ratio policy since it has more of an impact on personal income and hence consumption. Monetary policy does of course also affect housing market variables but also has a greater effect on the wider economy.

Catte et al. (2010) used NiGEM in work focused on the US over the period 2002 to 2007. They performed a number of counterfactual simulations to investigate two central elements of the world economy over this period, namely: (a) an over-expansionary US monetary policy and the absence of effective macroprudential supervision, which permitted a prolonged expansion of debt-financed consumer spending; (b) the decision of China and other emerging countries to pursue an export-led growth strategy supported by pegging their currencies to the US dollar, resulting in a huge build-up of their official reserves, in conjunction with sluggish domestic demand in surplus advanced economies characterized by low potential output growth.

They assumed in turn that a policy was feasible that would influence spreads on mortgages and showed that along with monetary policy tightening, this would have mitigated the housing cycle (reducing real house price rises by 1/3 over 2002–2007). However, growth would have been lower and the improvement in the current account deficit, though not trivial, would have presumably been too small to eliminate the risk of a disorderly correction. For that, a rebalancing of global demand via expansionary policies elsewhere would have been required.

6. Macroprudential policy in NiGEM

6.1. Systemic risk index

We extended NiGEM to include a systemic risk index which identifies when the financial system and economy show signs of needing macroprudential intervention owing to heightened risk of a financial crisis. This index drives the macroprudential policy levers (capital buffers and loan-to-value ratios) and is based on work by Barrell et al. (2010b) and Karim et al. (2013), where unweighted banking sector capital adequacy, the banking sector liquidity ratio, the change in real house prices and the current balance to GDP ratio drive systemic risk. Given the prominent role that the systemic risk function plays in our modelling of macroprudential policy in NiGEM, we briefly summarise their work in this section.

Barrell et al. (2010b) and Karim et al. (2013) utilised a multinomial logit to model the probability that a financial crisis occurs at any point in time. The dependent variable is a binary banking crisis indicator that takes the value of one at the onset of the crisis and zero otherwise.[5] The dataset includes data on systemic and non-systemic banking crises from 14 OECD countries drawn from the IMF Financial Crisis Episode database and the World Bank database of banking crises. The countries included in the analysis are: Belgium, Canada, Denmark, Finland, France, Germany, Italy, Japan, Netherlands, Norway, Spain, Sweden, UK and the US. The sample covers 1980–2006 (Karim et al., 2013) and 1980–2008 (for Barrell et al., 2010b) data.

The authors tested for the effect of up to eleven independent variables: current account balance to GDP ratio (CBR), real GDP growth (YG), inflation (INFL), change in real house prices (RPHG), the M2 to foreign exchange reserves ratio (M2RES), real domestic credit growth (DCG), unweighted banking sector capital adequacy (LEV), banking sector narrow liquidity to assets ratio (NLIQ), the real interest rate (RIR) and the fiscal surplus to GDP ratio (BB). Karim et al. (2013) also included a proxy for off-balance-sheet activity of banks (OBS). After the nested testing of the variables, with sequential elimination of insignificant variables, in each case only four variables remained: the current account balance to GDP ratio, the banking sector narrow liquidity ratio, the change in real house prices and unweighted banking sector capital adequacy. In Karim et al. (2013), OBS was considered to be proxied by house prices for the 1980–2006 estimation period.

There are strong economic arguments for the inclusion of each of these four variables in a systemic risk function. For example, capital protects banks against losses (it acts as a “buffer”), so higher capital increases banks' resilience to shocks. Lower capital makes them more vulnerable to shocks and also gives rise to incentives for risk taking. This in turn is due to moral hazard generated by the mispriced “safety net” of lender of last resort and deposit insurance. Liquidity ratios show banks’ robustness to sudden withdrawal by depositors. Increased house prices may give rise to higher borrowing without major increases in leverage, but levels may be unsustainable. House prices are also correlated with commercial property prices, trends in which link closely to fragility in the banking sector (Davis and Zhu, 2009); together they are key indicators of a credit-driven cycle.

A number of potential links can also be traced from current account deficits to risk of banking crises. Deficits may be accompanied by monetary inflows that enable banks to expand credit excessively and may link

[5] An alternative approach would be to consider a binary variable that takes a value of one whenever a country is in a banking crisis. However, this might bias the results as policy actions implemented during a crisis may have a direct impact on some variables of the regression model. For further discussion of this point see Demirgüç-Kunt and Detragiache (1998).

[6] Note that a similar frequency of crises obtains over a much longer period as in Boissay et al. (2013) who found a rate of 0.0449 crises per year over the 1870–2008 period for 14 OECD countries.

to economic overheating. Inflows may also both generate and reflect a high demand for credit, boosting asset prices in a potentially unsustainable manner. Such patterns may be worsened by lower real interest rates driven by inflows. Inflows to finance deficits may be sensitive to the risk of monetisation via inflation, and cessation of such inflows can disrupt asset markets and banks' funding.

OECD countries are usually seen as relatively less subject than emerging markets to such "sudden stops". However, as argued by McKinnon and Pill (1994), capital inflows in a weakly regulated banking system with a safety net may lead to booms in lending, consumption and asset prices as well as further increases in current account deficits. This pattern may lead on to exchange rate appreciation, loss of competitiveness and a slowdown in growth, as in the US in the middle of the last decade. It may also lead to a banking crisis, again much as we saw in the US in the late 2000s, although unlike for traditional "sudden stops" the currency did not collapse.

After comparing the alternative estimates from Karim et al. (2013) and Barrell et al. (2010b), we used the latter. Although it used less up-to-date data and shorter lags on banking sector variables, it did include the subprime crisis in the estimation. The specification is as follows:

$$Prob(crisis_t) = \frac{1}{1 + e^{-(-0.34LEV_{t-1} - 0.11NLIQ_{t-1} + 0.08RPHG_{t-3} - 0.24CBR_{t-2})}}. \quad (1)$$

LEV denotes the bank capital to total assets ratio, NLIQ is the narrow liquidity to total assets ratio, RPHG is the change in real house prices and CBR is the current account balance to GDP ratio. This equation provides a probability of crisis for each country based on differing levels of these variables, whereas being based on panel estimation the coefficients are the same across countries.

The in-sample accuracy of the model is impressive. As an illustration, as shown in Table 3, the logit model is accurate over 1980–2008 on 72% of occasions including the subprime crisis onset.

Subsequently, one needs to define a threshold value to indicate the point at which the probability of an economy suffering a financial crisis is large enough to warrant action from the authorities via macroprudential policy. The trigger point would lead to the authorities imposing loan-to-value ratio limits on the housing market via the mortgage demand function, or higher capital ratios.

Using actual values in the NiGEM for each country we calculate critical values for the probability of a crisis, which are used to trigger the macroprudential policies. These are 0.05 for Germany, 0.03 for Italy and 0.01 for the UK. We define these critical values as the probability of a crisis, according to Eq. (1), when LEV, NLIQ, RPHG and CBR are at their average levels over the sample period. Note that when the systemic risk index (*sri*) is above the critical value in a particular country, this implies that the probability of a crisis is elevated. We do not use *sri* to define a crisis period. It is of course possible for a crisis to occur when *sri* is low and conversely for the *sri* to be high without a crisis occurring.

The estimated *sri* is a function of lagged variables. However, we want the macroprudential tools to be activated as soon as it becomes apparent that the probability of a future crisis is elevated. Thus we have reduced the number of lags by one year so that the macroprudential tools are switched on at the first sign of danger. Accordingly, the effective lag on house price growth is 2 years, on the current account 1 year, and we take capital adequacy and liquidity as contemporaneous. The performance of the index is as set out in Table 3, but with a year lag. Note that our systemic risk index does not include credit as a leading indicator of financial crises. This reflects extensive research in earlier work (Barrell et al., 2010a and b, Karim et al., 2013) which shows that credit is not a significant predictor for OECD country crises when house prices, the current account, bank sector leverage and banking sector liquidity are included. The issue may be that credit rises may also accompany a booming economy and not necessarily a fragile financial sector. In contrast, work on global samples such as Demirgüç-Kunt and Detragiache (1998, 2005) typically does include credit as a determinant of banking crises.

In this context, Mallick and Sousa (2013) show that credit growth has been an important aspect of financial stress in the Eurozone, but that the right rate of credit expansion is hard to gauge. Our model does not require such an assessment but instead relies on the combination of the four above-mentioned crisis predictors. Schularick and Taylor (2012), using data from 1870 to 2008, suggest that credit contains valuable information about future crises, but also note that it is not a perfect predictor and that there may be reasons why, in some periods, credit expands to support real economic gains. In a subsequent paper, Jorda et al. (2013) showed that more credit-intensive expansions tend to be followed by deeper recessions (in financial crises or otherwise) and slower recoveries, implying that credit growth warrants close monitoring for this reason. Jorda et al. (2016) find predictive power for forms of credit in respect of crises in advanced economies, but do not include the alternative variables that Barrell et al (2010b) or Karim et al. (2013) find dominant over credit as a crisis predictor.

We did consider alternatives to a systemic risk index as outlined above, but found the index to be superior to the possible alternative triggers for macroprudential policy. For example, price-based measures might be considered as an alternative trigger, and there is a literature, for example, on the credit quality spread of government to corporate bonds as a cyclical predictor. However, with respect to financial crises, their predictive power is limited: the "efficient markets hypothesis", whereby prices convey all necessary information, may not hold. The failure of markets to internalise the cost and probability of the 2007–2009 systemic crisis is a case in point (Bennani et al., 2014).

In this context, the ECB has developed a Composite Indicator of Financial Stress (Hollo et al., 2012), which includes 15 stress indicators across 5 sector (money, bonds, equities, intermediaries and foreign exchange) which are in turn aggregated into the composite indicator using portfolio-theoretic principles. This would not be feasible for NiGEM given the series are generally not available; also it omits real economy aspects that we argue makes our own index superior. It also aims to show contemporaneous stress rather than being predictive. Mallick and Sousa (2013) employ the financial stress indicator of Carderelli et al. (2011) which again features price indicators which show the financial system is already under strain and intermediation is impaired, so again is largely contemporaneous.

Borio and Drehmann (2009) find that real asset price gaps (between actual indices and smoothed trends), especially property price gaps, proved useful in predicting banking crises. At the same time, they stress that indicators focusing exclusively on stock market prices would have failed to signal the build-up of risk as it was not correctly priced. Furthermore, most of the measures capturing banks' risk-taking that have been used in the literature, such as the expected default frequency (EDF), idiosyncratic bank volatility, the so-called Z-score, or banks' Value-at-Risk (VaR), work reasonably well for assessing risks in the cross sectional dimension but not so well in the time dimension (Dufrénot et al., 2012).

As a more viable alternative, we note the Bank for International

Table 3
In-sample accuracy of early warning model (Barrell et al., 2010b).

	Prob = 0.0555, Sample 1980–2008		
	Dep = 0	Dep = 1	Total
P (Dep = 1) ≤ Prob	247	5	252
P (Dep = 1) > Prob	97	15	112
Total	344	20	364
Correct	247	15	262
% Correct	71.80	75.00	71.98
% Incorrect	28.20	25.00	28.02

Source: Barrell et al. (2010b). Notes: Using the sample rate of crises per year (0.0555) as a cut-off.[6] Dep is the value of the binary dependent variable.

Settlements (BIS) work on credit-to-GDP gaps as a possible crisis predictor (see also the summary in Davis et al., 2017). As argued by Bennani et al. (2014), the credit-to-GDP gap, is particularly relevant for calibrating the countercyclical buffer (CCB) as it signals the build-up of risk sufficiently early, prior to financial crises (see, e.g., Drehmann et al., 2010; Drehmann et al., 2011). However, it may not be always a robust leading indicator of costly price booms or banking crises (Borgy et al., 2014). Repullo and Saurina (2011) argue that the credit-to-GDP gap ratio could exacerbate the inherent procyclicality of the risk-sensitive bank capital regulation. In addition, as the credit-to-GDP gap ratio corresponds to the deviation from a filtered trend, its real-time use depends mostly on the reliability of the end-of-sample estimates of credit and GDP. Some authors argue that subsequent revisions of macroeconomic statistics could be as large as the gap itself (Edge and Meisenzahl, 2011), which can raise concerns about the robustness of the credit-to-GDP gap if used as the sole indicator for CCB implementation.

We note that the "horse race" of indicators in Basel Committee (2010), which found the credit gap superior, did not include the output of any systemic risk function as an alternative. In the light of the discussion above and the work of Barrell et al. (2010b) and Karim et al. (2013), we prefer to use the *sri* function. We do however retain the credit-to-GDP gap as an alternative option. Other possible triggers could include borrower leverage, lending standards, debt-to-income ratios for households and corporations and exposure of households and corporates to interest rate and currency risks. However, the systemic risk index is our preferred method of triggering macroprudential policy.

6.2. Modelling macroprudential policy in NiGEM

This section lays out the general form of the macroprudential block in NiGEM. We describe the macroprudential levers, how they interact with our systemic risk index and the effects that macroprudential tools have on the economy. We then go on to outline components of the block in more detail in subsequent sections. A variable list is given in Appendix 1.

A growing literature (extensively surveyed in Carreras et al., 2016, 2018a) has pointed out that macroprudential tools are effective at curbing asset price and credit growth as well as ensuring minimum levels of bank capital or liquid assets to total assets. The work outlined in Section 6.1 above on modelling the probability of a financial crisis, as well as work on the costs of financial instability (see also Barrell et al. (2009); (2010c)) indicates that the aforementioned effects of macroprudential policy may indeed limit the likelihood of a costly crisis and subsequent recession taking place. However, the implementation of such policies is likely to increase the cost of financial intermediation. Thus, in this article, we explicitly take into account the beneficial effects of macroprudential policy on limiting the risk of a crisis taking place, while incorporating the costs as captured by the impact of macroprudential tools on the borrowing and lending spread and on house prices and subsequently on real activity.

Before delving into the details, we introduce in an informal manner the main ingredients and channels of the model underlying the macroprudential block. As noted, we consider two macroprudential variables: loan-to-value ratios on mortgage lending, and bank capital adequacy. The choice is based on work from Carreras et al. (2016, 2018a) who found loan-to-value ratios and variable bank capital adequacy to have a statistically significant impact on house prices and household credit growth in advanced OECD countries. Loan-to-value ratios are specific to the housing sector and impact the economy primarily via private consumption. By limiting the quantity of available credit for housing, this lever has an impact on house prices, which in turn impacts the aggregate consumption equation via a wealth effect.

Meanwhile, an important element of Basel III is discretion of the authorities in setting capital adequacy for macroprudential purposes, as discussed further below (Basel Committee, 2010, 2015). Bank capital adequacy acts on the spread between borrowing and lending rates of households and corporates, subsequently having an impact on private sector investment via its effect on the user cost of capital and on private consumption via an impact on house prices and real personal disposable income (*rpdi*).

The tools in turn impact on crisis probabilities by, for example, reducing house prices and improving the current account balance (as the economy slows), and building up bank capital and liquidity. However, the model, as it stands, is mean reverting with error correction equations, and does not typically generate crises itself. But crises can be imposed in NIGEM by the user, as for example in Hurst et al. (2016). In that paper the authors imposed an increase in spreads on the borrowing rates of sovereigns, firms and households, falls in equity markets and a reduction in consumer sentiment/confidence as in the EBA 2016 EU-wide banking stress test (ESRB, 2016).

6.2.1. Macroprudential tools

The loan-to-value ratio (*ltv*) is the first macroprudential lever that we include in the model. It takes the form of a discrete function whose value depends on our systemic risk index (*sri*). While nothing constrains the number of values that *ltv* might take, in our benchmark specification *ltv* is a binary variable that takes the value of zero or one, with unity representing a tightening of policy, which is triggered when *sri* exceeds a certain threshold value, $\overline{sri}$ (0.05 for Germany, 0.03 for Italy and 0.01 for the UK).[7] Easing can accordingly take place after the *sri* is below crisis levels. We have defined the *ltv* function in NiGEM to return to zero after *sri* has dropped below the critical value and remained below for 3 years. The 3 year lag is to prevent the policy being switched on and off if *sri* is fluctuating around its critical value, and to ensure that easing does not occur prematurely.

We note there could be a more gradual adjustment, whereby there are intermediate as well as maximum applications of the loan-to-value policy (so, it might first rise to 0.5 at an intermediate level before attaining 1 at crisis levels of *sri*). In addition, *ltv* can be set manually rather than being triggered by changes in *sri*, and in this case it may be set to values other than 0 or 1.

Target capital adequacy that banks will have to follow with their actual risk-adjusted leverage is also triggered by the systemic risk indicator. It constitutes the second macroprudential lever of the model. The way in which *sri* triggers the reaction function is different from the *ltv*, and occurs through the target risk-adjusted bank leverage variable *levrrt*. We follow the approach of the countercyclical buffer in Basel III, whereby the increase in capital adequacy in response to concerns about systemic risk can be up to a maximum of 2.5 per cent, although as noted in Basel Committee (2015), authorities can exceed this if they see fit. Generally authorities allow up to 1 year for banks to adjust to a rise in the CCB, but falls can be taken immediately.

We have modelled target capital adequacy such that in simulation, once *sri* rises above its critical value, *levrrt* immediately jumps to a level 2.5 percentage points above its baseline. This is accordingly in line with a full application of the countercyclical buffer. Similarly to *ltv*, once *levrrt* is triggered it remains 2.5 percentage points above baseline until *sri* has dropped below its critical value and remained there for 3 years, after which *levrrt* reverts to its baseline level. The risk-weighted capital-to-asset ratio, *levrr*, adjusts gradually in response to the change in *levrrt*, as discussed in Section 6.3. We consider our *sri* function to be a superior trigger to the credit/GDP gap that is recommended by the Basel Committee (2015), as discussed above.

Note that use of the risk-adjusted capital to asset ratio (*levrr*) and its

[7] The formulation of *ltv* as a zero-one variable follows the IMF database of macroprudential instruments presented in Cerutti et al. (2017)), which has zero for "policy off" and one for "policy on". The coefficients for the *ltv* effects on house prices and household liabilities are derived from estimates in Carreras et al (2016, 2018a) using the IMF database in up to 19 OECD countries. The coefficients show the effect of an average intervention across the countries concerned.

target (*levrrt*) are in line with the existing work on NiGEM such as Davis and Liadze (2012) as discussed further below, as well as with the current regulatory regime which focuses on risk weighted assets. This is accordingly distinct from the actual estimates of the *sri* set out above that used unweighted capital/assets. However, as shown in Barrell et al. (2009), who adopted a similar approach to us, the correlation coefficient for weighted and unweighted capital ratios is 0.92.[8]

Finally, note that the inclusion of the capital adequacy ratio in the *sri* function means that the policy of increasing capital adequacy requirements has a direct effect of reducing systemic risk, while the effect of *ltv* on systemic risk is indirect, mainly arising via lower house prices than would otherwise be the case albeit also raising bank capital adequacy. The current account also improves after application of each of the tools, as does bank liquidity (not illustrated in the charts).

6.2.2. Modelling spreads

Spreads are assumed to be driven by capital (as a cost to banks) but not by *ltv*. The household lending wedge (*lendw*) is driven by the net wealth to household income ratio (*nwpi*), the bank capital to risk-weighted total assets ratio (*levrr*) and the rate of household mortgage arrears (*arr*).[9]

$$lendw = f(nwpi,\ levrr,\ arr) \tag{2}$$

A change in the capital adequacy target (*levrrt*) affects the household lending wedge (*lendw*) indirectly via its effect on *levrr*, which moves towards the target level (see Eq. (11) below).

The overall corporate lending wedge (*iprem*) is set equal to the bank lending spread *corpw,* assuming bond finance is priced similarly to bank finance; the wedge on bank lending to corporates is also affected by inverse headroom (as discussed below), capital adequacy (*levrr*), the corporate insolvency rate (*insolr*) as well as the cyclical state of the economy denoted by the actual output to potential output ratio (*y/ycap*).

$$iprem = corpw = f\left(\frac{y}{ycap},\ insolr,\ levrr,\ 1/headroom\right) \tag{3}$$

Headroom is the difference between banks' level of capital adequacy (*levrr*) and that required by the authorities (*levrrt*). The latter is affected by the normal Basel level of 8 per cent of risk-adjusted capital adequacy plus any additional requirements of the authorities, as in the UK, and further additions such as the Basel III countercyclical buffer as discussed above. These all affect *levrrt,* while losses and capital building, as well as assets and their composition, affect *levrr*.

$$headroom = levrr - levrrt \tag{4}$$

The systemic risk indicator *sri* feeds directly into the target level of capital adequacy in the manner as noted above, which in turn feeds into both *iprem* and *lendw*. The working of this is as discussed above

$$levrrt = f(sri) \tag{5}$$

6.2.3. Modelling house prices and credit

The two macroprudential tools we include in the model affect sectors in the economy in a different way. Focusing first on the loan-to-value ratio (*ltv*), this tool primarily targets the housing market. In NiGEM, the housing market is described by a price (supply) equation, p_H, and a demand equation for mortgages. Loan-to-value ratios, by imposing a constraint on the quantity of mortgages supplied in the market, can potentially, through market clearing, affect house prices.

Household liabilities are split between consumer credit and mortgages, both of which are endogenously determined. Given that the household lending wedge *lendw* already appears in the existing equation for mortgages, we consider a simple expansion of the existing mortgage equations to include *ltv* with calibrated coefficients based on the estimates in Carreras et al. (2016, 2018a):

$$morth/ced = f(rpdi,\ lendw,\ lrr,\ rph,\ ltv) \tag{6}$$

where *morth/ced* denotes outstanding mortgage liabilities in real terms, *rph* denotes real house prices and the remaining variables have been defined previously. The nominal counterpart to *morth* then feeds into total household liabilities *liabs*. Consumer credit is not affected directly by *ltv* limits, which are specific to mortgage lending.

House prices (*ph*) are affected indirectly by macroprudential policy in terms of the lending spread to households (price effect of capital requirements) and by the loan-to-value ratio tool (quantity effect of *ltv*), again with the calibrated coefficient being based on the estimates in Carreras et al. (2016, 2018a).

$$ph = f(lendw,\ lrr,\ ced,\ ltv) \tag{7}$$

In addition, house prices are also determined by the long-run real interest rate (*lrr*) and the price level (*ced*) in order to control for supply side dynamics[10]. Note that besides its direct impact, the lending spread *lendw* also impacts indirectly on households via net interest income. Meanwhile, the housing stock does not affect house prices in a backward looking simulation. The equations for housing investment are driven by GDP, population, the user cost of capital and the lagged capital stock. Accordingly, housing investment, like other investment, is affected inter alia by growth but also by changes in spreads which affect the user cost of capital but not by house prices.

To summarise, the existing equations in NiGEM for house prices and household liabilities were amended to incorporate the changes laid out in this section. Note that other asset prices (equity prices, bond yields, exchange rates) are not affected directly by the macroprudential tools.

6.2.4. Impacts on consumption and investment

The loan-to-value tool affects consumption by directly reducing both lending and house prices.

The capital adequacy tool has an impact on private investment by acting on the lending spreads of corporates, as well as indirect effect on consumption via house prices and thus wealth as household lending spreads adjust.

Consumption (*c*) is affected by housing wealth (*hw*), which in turn is driven by house prices, and by net financial wealth (*nw*) which is affected by total outstanding liabilities. As a result, macroprudential policy has an impact on private consumption via the wealth effect coming through its impact on both house prices and household liabilities. It also impacts via net interest income generated by changes in the household lending spread *lendw* which affects *rpdi*.

$$c = f(rpdi,\ nw,\ hw) \tag{8}$$

Corporates are affected by capital adequacy as the movements in the corporate lending spread, *corpw*, triggered by *sri*, has an impact on private sector investment via the user cost of capital. Investment is not affected directly by *ltv* policy.

[8] They also noted "If we regress the weighted capital ratio on a constant and an unweighted capital ratio for the UK the coefficient on unweighted capital is 1.0007 with a standard error of 19.6 and hence there is no problem in linking our results in this section [banking sector modelling] with those in the section above on the causes of crises" (Barrell et al., 2009, p26).

[9] Note that arrears and insolvencies are not currently modelled in NiGEM as a feedback mechanism from the economy to the financial system but purely as a random walk.

[10] The house price equation is backward looking by default. In forward looking mode, house prices are also affected by real personal disposable income (*rpdi*) and the housing capital stock (*kh*).

6.3. Modelling the banking sector in selected countries in NiGEM

Further channels of macroprudential policy are available in the models for Germany, Italy and the UK where the banking sector is explicitly modelled.[11] The modelling of banking sectors' influence in terms of spreads between borrowing and lending rates, in a global macroeconomic model, was pioneered by NIESR in its work on the impact of capital adequacy regulation (Barrell et al., 2009), where other influences on spreads besides capital include measures of borrower risk. Goodhart (2010) has argued that determining spreads is precisely the way that banks should be incorporated in macroeconomic models, and not either ignored or set out in terms of the "money multiplier", see also Woodford (2010).

As described in Davis and Liadze (2012), we model banking activity as a set of supply (or price) and demand curves. Demand depends on levels of income or activity, and on relative prices, whilst supply, or price, depends upon the costs of providing assets and on the risks associated with those assets. The core of the banking model are the above-mentioned equations for spreads between borrowing and lending rates for households and corporates, setting of which we consider, in line with Goodhart (2010) and Tobin (1963) to be the best description of how banks operate - setting deposit and lending rates at levels sufficient to cover losses and generate profits and then accepting the resulting quantities of deposits and loans. The fact that spreads are partly driven by balance sheet constraints in respect to capital means there are also some parallels to the financial accelerator, i.e. Bernanke et al. (1999) and Gertler and Karadi (2011).

The banking sectors in the model have four main assets, secured loans to individuals for mortgages, (*morth*) with a borrowing cost (*rmort*) affected in part by the markup applied to household loans by banks (*lendw*) as shown above, unsecured loans to individuals for consumer credit (*cc*) with a higher borrowing cost or rate of return (*ccrate*) again affected by the household margin. Then there are loans to corporates (*corpl*) with a rate of return or cost of borrowing ($lrr + corpw$) where *lrr* is the risk free long rate and *corpw* is the mark up applied by banks (*iprem* is set equal to *corpw,* as noted above). The whole balance sheet of assets (*bbal*) can then be derived by adding in liquid assets (*bra*) which are modelled as a fixed percentage of the balance sheet and other assets (*bbsoa*), which rise in line with total lending.

$$bbal = corpl + morth + cc + bra + bbsoa \tag{9}$$

This is the denominator of unadjusted capital adequacy. Given the balance sheet of assets, we can also estimate the risk-adjusted balance sheet (*brwa*) by applying broad risk weights to the different assets. This is then the denominator of *levrr* (risk-adjusted capital adequacy). We assume that mortgages have a risk weight of 0.5, liquid assets 0.2, other assets 0.3 and consumer credit and corporate loans have a risk weight of 1.0.

$$brwa = corpl + 0.5{*}morth + cc + 0.2{*}bra + 0.3{*}bbsoa \tag{10}$$

Assuming, then, that assets equal liabilities, we can calculate the components of liabilities, namely deposits (driven by M1), other liabilities (growing in line with nominal GDP), wholesale deposits (a residual, in line with the practice of banks to use this as a residual source of funds) and capital itself (as shown in Eq. (11) below). The sum of these variables is liabilities, which is set equal to assets. Accordingly, we can derive total on-balance sheet bank activity within the UK, Italy and Germany.

Concerning the framework for capital adequacy, if there is a shock to any of the assets of the banking system then *levrr* changes, and banks are obliged to adjust either their capital or their asset structure. Capital can either be raised by rights issues or by absorbing some of the gross operating surplus of the system.

$$bcap = bcap_{t-1} + \left(1 - \frac{levrr_{t-1}}{levrrt_{t-1} + 3}\right){*}15{*}\left(\frac{lendw_{t-1}}{400}{*}(morth_{t-1} + cc_{t-1}) + \frac{corpw_{t-1}}{400}{*}corpl_{t-1}\right) \tag{11}$$

The expression inside the first set of brackets in Eq. (11) gives the speed of adjustment for bank capital. As *levrr* is the risk weighted ratio of capital to assets, or *bcap* divided by risk weighted assets, *brwa*, we can calibrate the adjustment of *bcap* in line with the speeds of adjustment for the UK discussed in Osborne (2008), which is also applied to Germany and Italy. To achieve this we multiply the shortfall indicator by a calibrated adjustment factor of 15, as shown above. If *levrr* is below its normal level, given the desired level of headroom over 8 per cent, namely 3, some of bank income will be used to rebuild bank capital and increase headroom, and operating margins on consumer lending will be increased to speed up the process. The gross operating surplus of the banking system is the gross margin on the three types of lending multiplied by the total value of the stock of the particular category of lending, as illustrated in the expression inside the second set of brackets. Note that we do not assume that capital can be rebuilt simply by new capital issues, although we acknowledge that these occur at times, as do government recapitalisations in the wake of banking crises.

Changes in the speed of adjustment in this equation change the short run, but not the long run effects of changes in capital adequacy targets. As noted, arrears and insolvencies are not modelled currently in NiGEM to provide feedback from the real economy to the financial sector, which would otherwise lead this equation to also reflect the losses imposed on bank capital by corresponding defaults.

Then if regulation is tightened, for example via higher capital adequacy requirements as in Basel III, increased margins and reduced lending both move banks back toward their desired capital ratio. If the capital adequacy target ratio (*levrrt*) rises then risk weighted capital adequacy (*levrr*) increases and so does the cost of corporate and personal sector borrowing. These in turn raise the gross operating surplus that can be devoted to rebuilding capital, and reduce assets which raises *levrr* via a smaller denominator.

In the UK, for example, there has been a normal excess above the required minimum level of capital adequacy, which has averaged 3 percentage points in this sample, with a corresponding difference applied in Italy and Germany. As the difference between actual and target levels of risk-weighted capital to asset ratios shrinks, we might expect banks to push up their borrowing charges. As headroom goes to zero we would expect there to be significant non-linear increases in borrowing costs. In order to capture this we included inverse headroom in the corporate wedge equations, as shown above. However, in general the banking sector amplifies booms via its impact on the real economy to a limited extent, reflecting results of estimation. We note that stronger amplification would be contrary to model stability.

7. Key variables

In this section we show and comment briefly on the variables that influence the systemic risk function over the period 1997–2016.[12] These are banking sector risk-adjusted capital to asset ratio (*levrr*), banking sector liquidity ratio ($liq = bra/bbal$), the change in real house prices (*rphg*) and the current account/GDP ratio (*cbr*).

As shown in Chart 7.1, the risk-weighted capital to asset ratio was relatively flat from 1997 to 2007 despite the increasing risk of financial instability. A slight upward trend is apparent in Germany from around 8 to just over 10 per cent, while in the UK the ratio fluctuated around 15

[11] Details of the implementation of macroprudential policy in countries where there is no banking sector are given in Carreras et al. (2018b).

[12] All variables referred to here come from the NiGEM database.

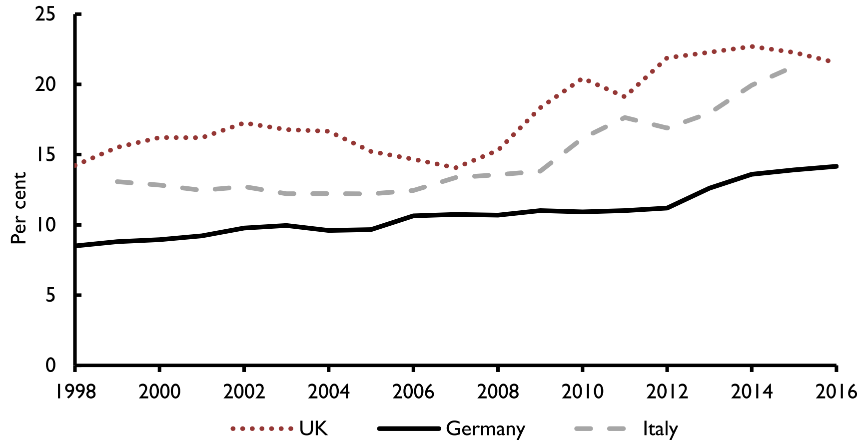

Chart 7.1. Bank risk-adjusted capital adequacy (*levrr*).
Source: NiGEM database

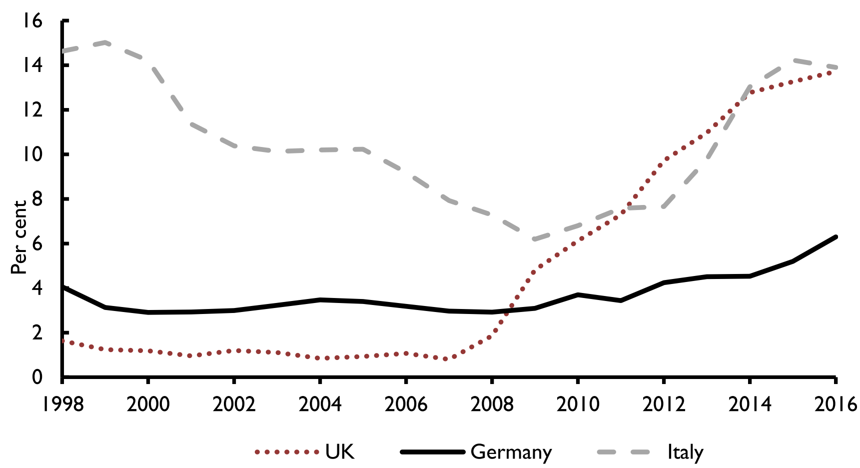

Chart 7.2. Bank liquidity ratio (*liq* = *bra*/*bbal*).
Source: NiGEM database and authors' calculations

per cent (reflecting partly the higher trigger ratios applied in that country bank-by-bank). Italian banks had ratios that were at an intermediate level of around 12.5 per cent. Since 2007 the ratio has increased over time, in line with Basel III, but according to our data this is much more apparent for Italy and the UK than for Germany. The UK and Italian ratios are around 20–25 per cent in the period since 2015, whereas the German ratio rose only to around 14 per cent at the end of the period. It needs to be borne in mind in assessing these data that the risk-adjusted ratio itself is an imperfect measure of bank risk, especially under Basel II, in the run-up to 2007. This was because subprime assets were given inappropriately

Chart 7.3. Real house price growth (*rphg*).
Source: NiGEM database

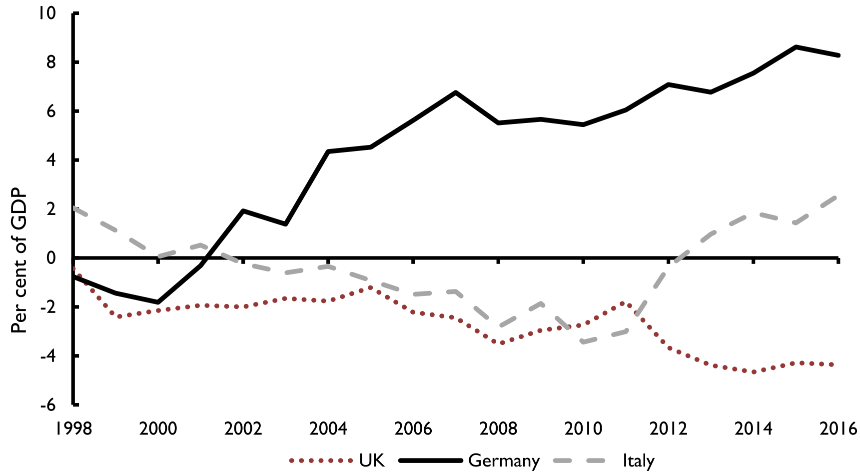

Chart 7.4. Current account/GDP ratio (*cbr*).
Source: NiGEM database

low risk weights following generous credit ratings being obtained for them.

Turning to liquidity (Chart 7.2), the measure shown suggests marked cross-country differences. Prior to the crisis, the ratio in the UK and Germany was quite low, at around 1 per cent for the UK and 3 per cent for Germany. In contrast, Italian banks held high but declining liquidity according to this measure, falling from 15 per cent in the late 1990s to 8 per cent in 2007 and 6 per cent in 2009. Again in line with Basel III and banks and regulators' preparation for it, as well as in response to the crisis and the overreliance on unstable wholesale funding, the ratio rose sharply over 2009–2017. By the end of the sample, it reached around 14 per cent in both the UK and Italy, while in Germany, the ratio climbed only to 7 per cent.

House prices (Chart 7.3) show greater volatility in the UK compared to Italy and especially Germany, where annual changes fluctuated around zero prior to 2010, after which a steady rise was seen. There were noteworthy falls in the UK over 2008-9 and in Italy over 2009–16.

Current account imbalances (Chart 7.4) were greatest in Germany in respect of the surplus that prevailed from 2002 onwards. In the UK there has been a persistent deficit, likewise in Italy from 2002 to 2011, after which a surplus was achieved.

The pattern of the systemic risk index *sri* is influenced by all four variables shown above (Chart 7.5), but given the coefficients as shown in Eq. (1) and the size of the variable, risk-adjusted capital ratios have a particularly strong effect. The *sri* indicates the output of the logit equation which needs to be interpreted in the light of crisis probabilities, which was 5.55% for OECD countries over 1980–2008 (Barrell et al., 2010b).

The period prior to the 2007 crisis showed a strong rise in the ratio in the UK, and to a lesser extent in Italy, thus giving some advance warning of the crisis. In the case of the UK, this was driven particularly by house prices and the current account, since capital and liquidity did not change much, while in Italy the decline in liquidity had a marked effect, as did the current account and house prices. The very high levels in Germany in the late 1990s reflect the weak data for bank risk measures shown above, offset later by the improving current account and relatively stable house prices. In the years since the crisis it is notable that for all the countries, this measure has been declining, and since 2015 has typically been close to zero per cent. This pattern largely reflects the improvement in banking risk measures following the regulatory tightening of the crisis and Basel III, as well as the lower rates of change in house prices.

8. Simulations

In order to evaluate the effects of the two alternative macroprudential tools on the wider economy, as well as assessing the potential benefit had macroprudential policy been available prior to the subprime crisis, we undertook three sets of simulations for Germany, Italy and the UK. Note,

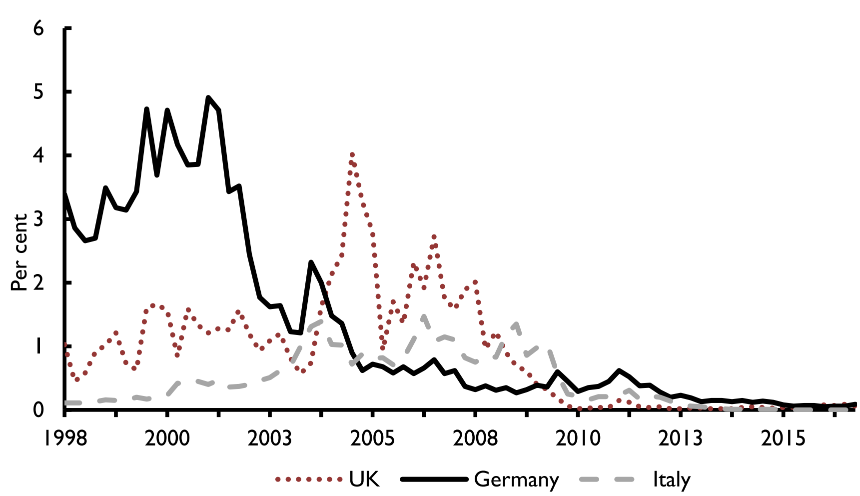

Chart 7.5. Patterns of systemic risk (*sri*).
Source: NiGEM database and authors' calculations

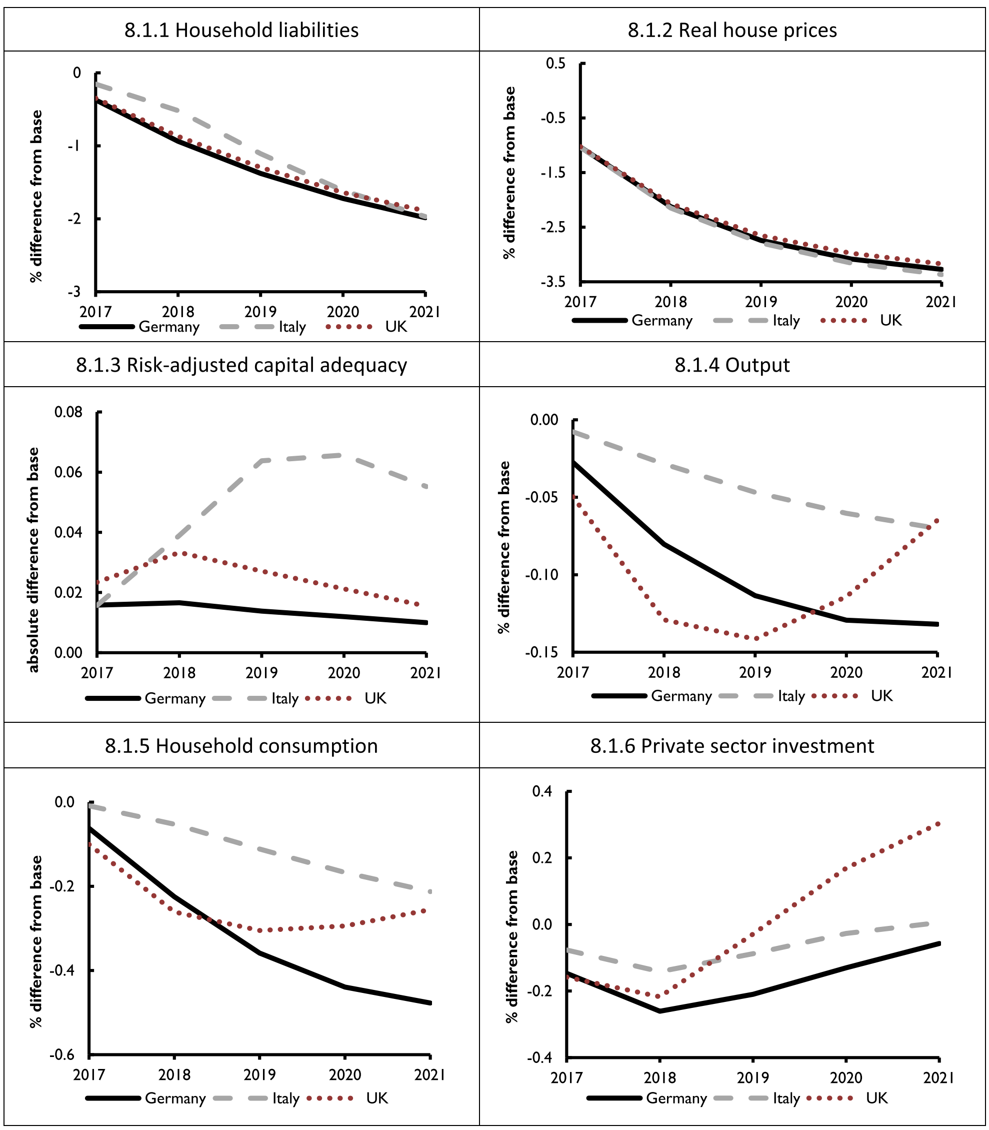

Chart 8.1. Simulation 1: tightening of loan-to-value policy.

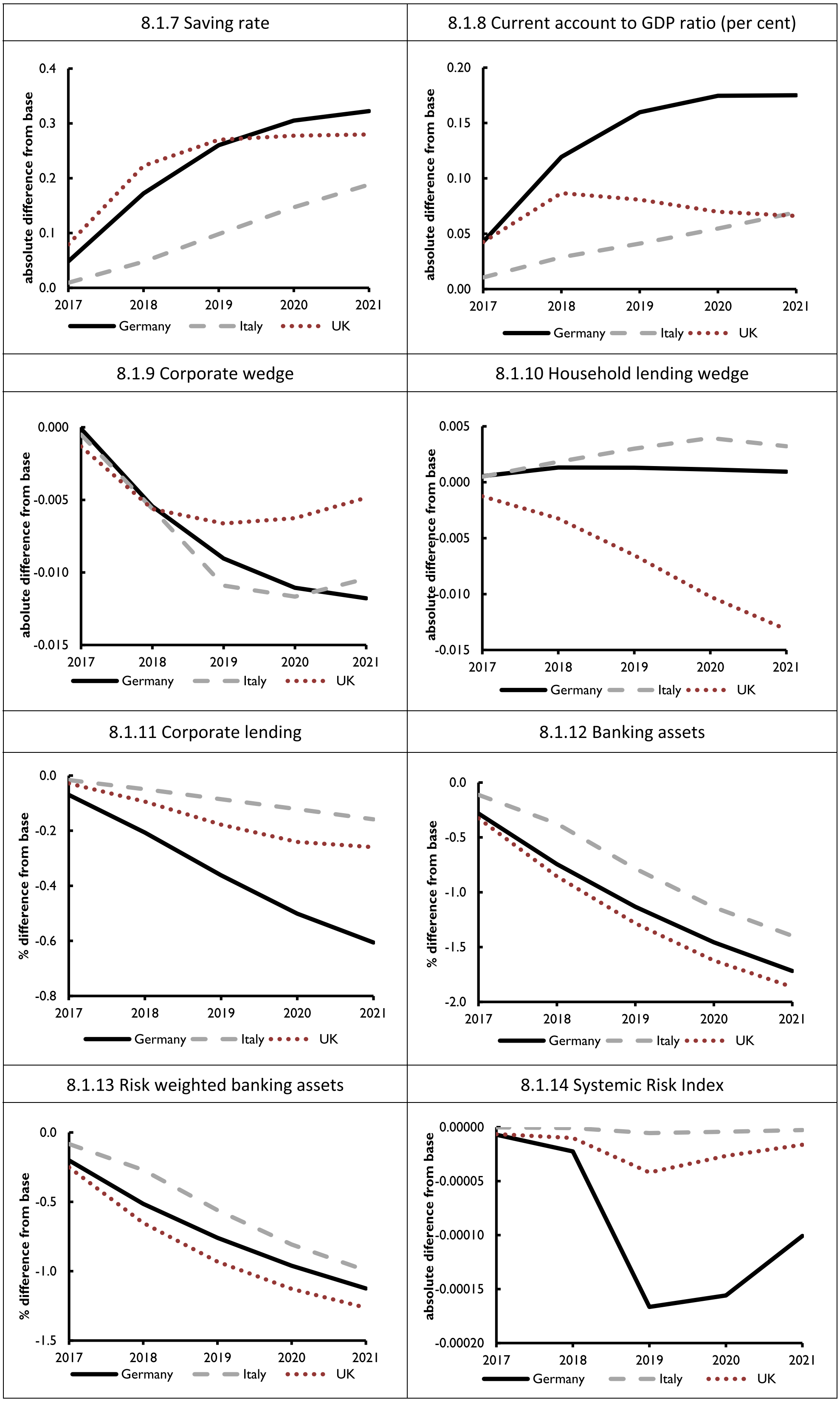

Chart 8.1. (*continued*).

that in the two policy simulations the shock is permanent, i.e. the macroprudential tools are switched on and do not respond to changes in the *sri*. On the other hand, for the crisis mitigation the model is allowed to operate, so that policies are triggered by the level of the *sri* and then removed three years after the *sri* falls below its critical level.

Simulation 1. Tightening of Loan-to-value(*ltv*) policy - we assess the impact of imposing tighter loan-to-value limits on the housing market on a permanent basis.

Simulation 2. Tightening capital adequacy policy – we permanently raise the target risk-adjusted capital adequacy by 2.5 percentage points, which represents the effect of imposing Basel III countercyclical buffer fully.[13]

Simulation 3. Crisis mitigation – this is a historic dynamic simulation over the subprime crisis period. We allow both the macroprudential policies to be triggered by the level of the systemic risk indicator from 2004. As noted, critical values for *sri* are 0.01 in UK, 0.03 in Italy and 0.05 in Germany (derived from sample averages). When *sri* rises above the critical value, the macroprudential tools are activated and remain "on" for 3 years after *sri* has fallen below the critical value.

Note that in our earlier work we also undertook a simulation for a combined simulation of both policies (i.e. general macroprudential tightening where we combine the two policies, imposing higher *ltv* limits and raising the countercyclical buffer simultaneously). For the sake of brevity, detailed charts of this simulation are not included in the current article; given the largely linear nature of the model,[14] the results are broadly additive (charts and description are shown in Carreras et al., 2018b). We do, however, include the general macroprudential tightening in the cost/benefit analysis in Section 9 below.

We show the responses of the economies of Germany, Italy and the UK in the charts below. Comments on the patterns follow. Note that we exogenise the monetary response, which means that interest rates do not react to the deviations from inflation and nominal targets, so we can isolate the effect of the macroprudential policy. Simulation results with endogenous monetary policy are presented in Carreras et al. (2018b), showing the effects of endogenous monetary policy are relatively minor. Meanwhile, fiscal policy follows a default feedback rule which ensures that the deficit achieves an equilibrium trajectory by using the direct tax rate as an instrument. Simulations were done one country at a time, apart from the historic dynamic simulation, where we simulated the effects on all three countries simultaneously.

By default, financial markets in NiGEM are forward looking, as are factor markets (as described in Section 4). All of these may be affected by changes in financial regulation. Changing the spread between borrowing and lending rates for individuals changes their incomes, and can also change their decision-making on the timing of consumption. Changing the spread between borrowing and lending rates for firms may change the user cost of capital and hence the equilibrium level of output and capital in the economy in a sustained way. A further important effect is of lower expected inflation on long rates, which means that there is a partial offset to any increase in the user cost of capital on investment arising from the corporate wedge.

8.1. Simulation 1: tightening of loan-to-value policy

The first simulation is the tightening of loan-to-value (*ltv*) policy. We see from Chart 8.1.1 that household liabilities decline in every country in the sample by around 2.0 per cent after 5 years. We note, however, that mortgage lending is not sizeable in Italy (or Germany) relative to GDP (around 60 per cent debt/income ratio for households) as compared to the UK (110 per cent). Equally, house prices fall in each country by around 3–3.5 per cent over the same period (Chart 8.1.2). These results for lending and house prices are to be expected since we have applied a direct exogenous shock to *ltv* in each of the relevant equations, in line with estimates in Carreras et al. (2016, 2018a). On the other hand, the patterns of bank capital adequacy and GDP growth are more varied. We see from Chart 8.1.3 that the risk-adjusted capital to asset ratio rises in each case, but only marginally in Germany and the UK by about 0.04 percentage point and by a larger 0.07 percentage point in Italy. This reflects the changing size and pattern of bank assets over the period following the shock.

The policy has a contractionary impact on GDP, albeit a fairly marginal one, with output falling by around 0.05–0.15 per cent at the trough. The components of this are shown in the subsequent charts. We see from Chart 8.1.5 that, after five years, consumption falls quite markedly by 0.2–0.5 per cent in all three countries. This reflects the wealth effect of falling house prices following the increase in the *ltv* ratio and households' need to save for deposits. However, dynamic patterns differ, reflecting different speeds of adjustments to the shocks in the economies. The fall in output depresses investment and in the short term private investment drops by about 0.2 per cent (Chart 8.1.6). However, in the medium term there is a partial recovery in investment. In this context, note that Italy has a smaller output decline than the other countries. Underlying this, it has a lesser fall in consumption and also initially investment than Germany and the UK, reflecting the estimated properties of the model. The fall in consumption generates a marked rise in the saving ratio of up to around 0.3 percentage point (Chart 8.1.7), which is to be expected since the *ltv* policy requires households buying property to save more for a deposit. The current balance improves (Chart 8.1.8), largely due to the fall in domestic demand, but also following improvement in real competitiveness reflecting a reduction in domestic prices. Given that monetary policy is deactivated in the simulations, nominal exchange rates (vis a vis the dollar) do not change.

Looking at the banking and financial market effects of the policy, the lending wedges for corporates and households are relatively unaffected by the loan-to-value policy so changes are quite small (Charts 8.1.9 and 8.1.10). This policy affects the volume of credit and not its price, and bank assets fall both on an unweighted as well as weighted basis by 1.5 and 1.4 per cent, respectively (Charts 8.1.12 and 8.1.13). The decline in risk-adjusted assets is smaller than that of the unweighted measure, as mortgages have a relatively low risk weight.

Finally, the policy has a negative effect on the systemic risk indicator for the UK and Germany but not to a significant degree in Italy (Chart 8.1.14). The differences in *sri* are driven largely by the different effects on risk-adjusted capital adequacy, which has a considerably greater effect than house prices or the current account (both of which also move favourably for financial stability) in the equation. However, it should be taken into account that the baseline *sri* in Italy is very low owing to the levels of capital and liquidity being high while house prices are stable. These means that the amount by which the Italian *sri* can improve is highly limited (zero is the lower bound to the *sri* index). This implies in turn that, according to the model, macroprudential policy is less needed for financial stability in that country as long as that configuration persists.

8.2. Simulation 2: increase in risk-adjusted capital adequacy target

Moving to the second simulation on tightening capital adequacy policy, Chart 8.2.1 shows that there is a decline in household liabilities, driven by the overall downturn in the economy (Chart 8.2.4) and the rise in the household lending wedge (Chart 8.2.10). House prices also decline, after rising initially, being affected by the increase in lending wedge, but by much less than in the loan-to-value scenario (Chart 8.2.2). We see from Chart 8.2.3 that risk-adjusted capital adequacy rises in line with the target set by the authorities, by 2.5 percentage points, with a lag, as is permitted by the Basel rules.

For Germany and Italy, GDP falls in this scenario to a much greater degree than in the *ltv* case, while the fall in the UK is comparable (Chart 8.2.4). Looking at the components, we see that both consumption and investment decline. However, compared to the previous scenario, the impact on consumption is smaller, while the impact on private

[13] Due to the forward looking nature of financial markets in the model, long term interest rates decline from the very first period of the simulation, which stimulates investment. To offset this, we increase the user cost of capital in the first period of the simulation.

[14] There are some nonlinearities, for example when hitting the lower bound for nominal interest rates and as headroom goes to zero.

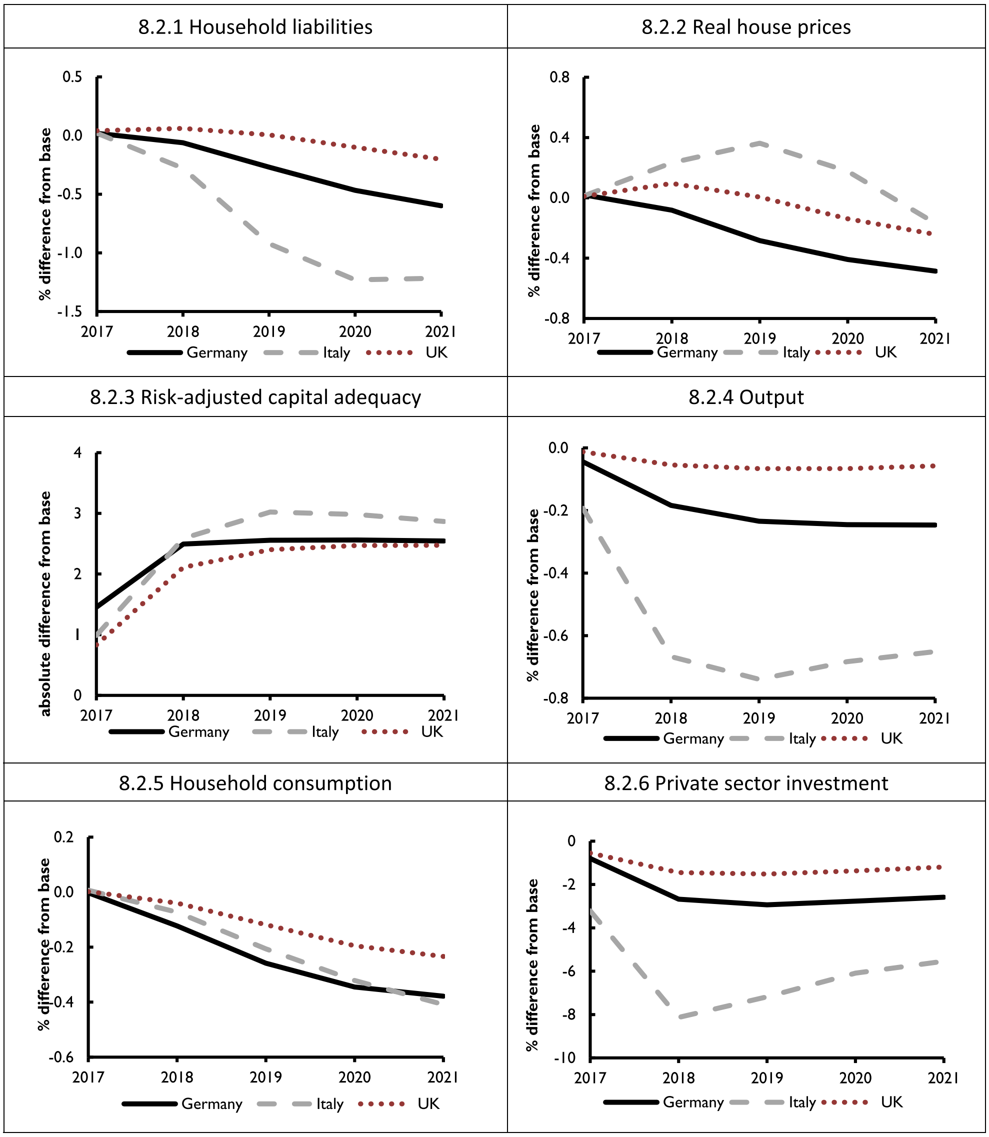

Chart 8.2. Simulation 2: increase in risk-adjusted capital adequacy target.

investment is markedly larger. Private investment falls more in Italy than in the UK and Germany (Chart 8.2.6), in the light of relative rises in the corporate lending wedge (Chart 8.2.9) and declines in other components of GDP. Results of estimation mean that the corporate lending wedge in Italy is more sensitive to changes in the capital adequacy target ratio (*levrrt*). It thus rises more than that in Germany and the UK in this scenario, causing the greater fall in investment and output. The saving ratio falls as real personal disposable income declines more than consumption, again markedly so in Italy (Chart 8.2.7). This reflects a greater decline in real personal disposable income (the denominator of the saving ratio), which in turn is caused by the larger decline in output and thus in employment due to lower investment. Similar to the previous case, it is not surprising to see an improvement in the current account balance, notably in Italy, as domestic demand decreases following the introduction of higher capital requirements (Chart 8.2.8).

As regards the financial patterns, the corporate wedge rises in each country, stabilizing at around 0.5–0.7 percentage points above base after five years (Chart 8.2.9). The household wedge rises rather less, by around 0.15–0.2 percentage points (Chart 8.2.10). These patterns are driven by the higher levels of capital required for banks, which affect banks' costs and are present in the equations for the wedges. Corporate lending falls to a much greater extent than lending to households (Chart 8.2.11, compare Chart 8.2.12), by 6 per cent, in line with the greater rise in the wedge for companies. Note however, that corporate lending does not drive investment, and hence the similar fall in lending in Germany and Italy can be reconciled with a greater fall in investment in Italy due to the wider spread in the latter country. Bank assets fall to a greater extent than in the case of implementation of tighter *ltv* policy for all three countries, but the fall is greater in Germany and Italy than the UK (Charts 8.2.12-8.2.13). The decline is comparable for both risk weighted and unweighted capital adequacy, since the brunt of the shock is taken by corporate lending with a risk weight of 1. Finally, the systemic risk indicator falls by more than in the *ltv* case for the UK and Germany, reflecting the key influence of bank capital adequacy on systemic risks (Chart 8.2.14), although again the ratio in Italy is little affected. Note that the scales on the *sri* charts 8.1.14, 8.2.14 and 8.3.14 differ.

As an interim summary, we can see that the loan-to-value simulation impacts largely on consumption and the housing market, whereas the

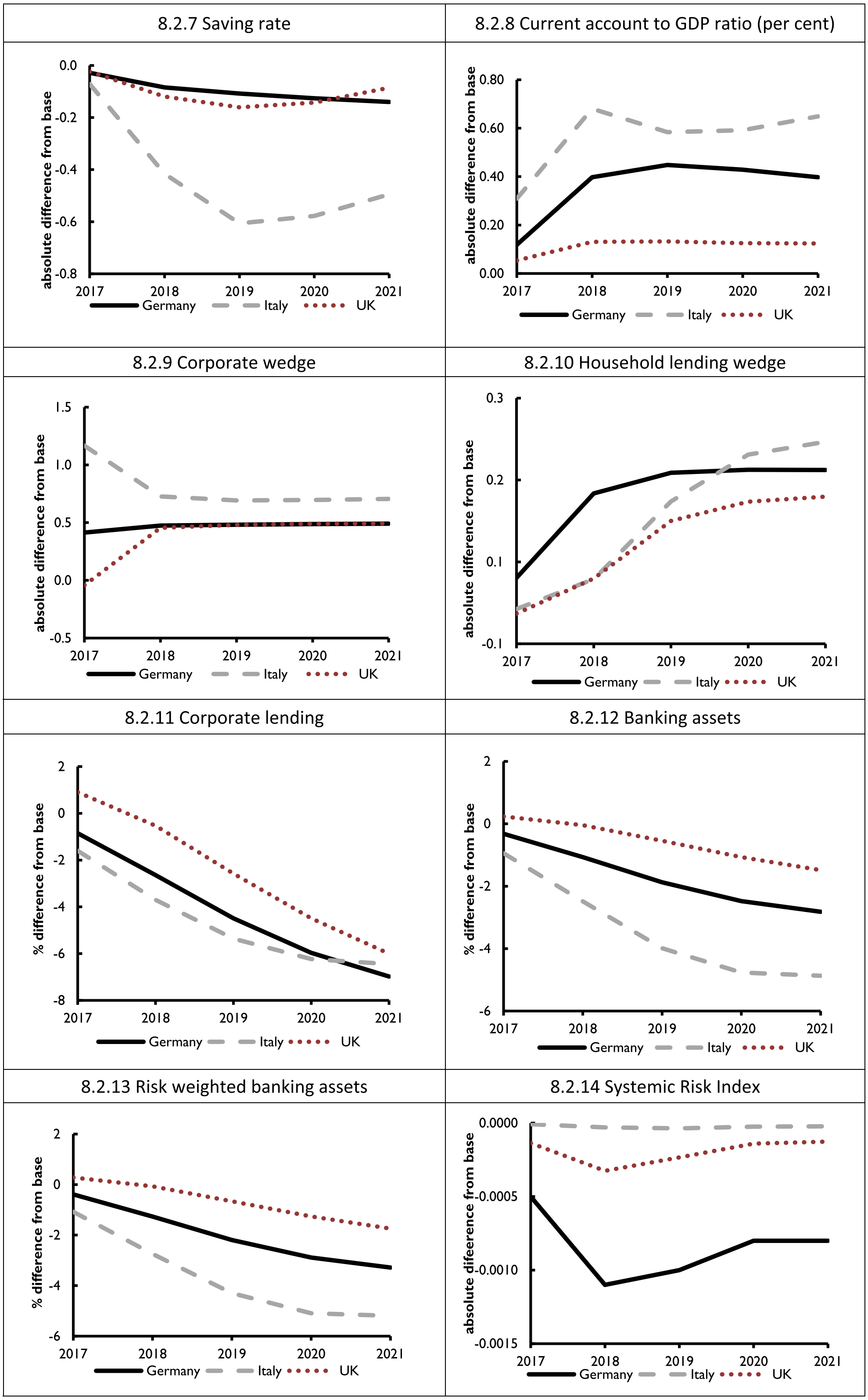

Chart 8.2. (*continued*).

capital adequacy simulation has a greater effect on investment and overall output. Both simulations raise bank capital ratios and lead to a decline in bank lending. The impact on crisis probabilities of the loan-to-value simulation arises mainly from lower house prices (albeit also leading to higher bank capital ratios) while the capital adequacy simulation raises bank capital adequacy directly. Both also entail an improving current account balance (as the economy slows), and a rise in bank liquidity ratios (not illustrated in the charts). On the other hand, there are also cross-country contrasts with the loan-to-value simulation having a greater relative effect on the UK and the capital adequacy simulation on Germany and Italy. Accordingly, the simulations show that authorities need to consider carefully not only the source of the concern

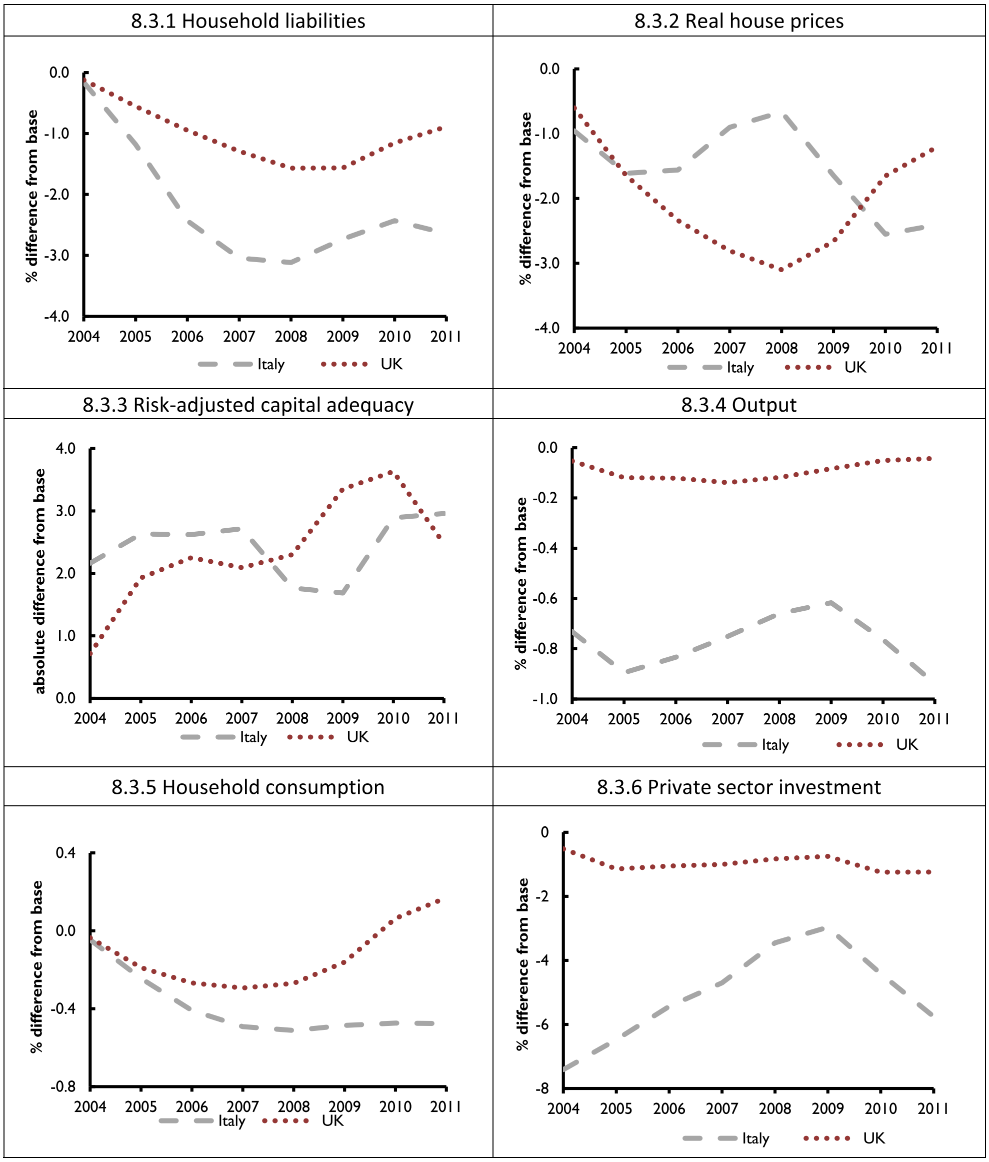

Chart 8.3. Simulation 3: Historic dynamic simulation for the crisis period.

for financial stability but also the financial structure and transmission mechanisms of the economy.

8.3. Simulation 3: historic dynamic simulation for the crisis period

The final simulation provides a historic dynamic simulation over the subprime crisis period. We allow the macroprudential policies to be triggered by the level of the systemic risk indicator from 2004. The simulation is most relevant for the UK and Italy, as the systemic risk indicator does not reach critical levels in Germany and hence the macroprudential tools are not triggered. German banks suffered from a crisis less due to domestic conditions than due to the US securitised bonds that they had purchased. The small impact that does arise in Germany (not illustrated in the charts) reflects the cross-border effect of the macroprudential policy changes in the UK and Italy on its economy.

By triggering the macroprudential policies in 2004,[15] three years ahead of the crisis, the UK and Italy would have had lower levels of household debt (Chart 8.3.1) as well as slower house price growth (Chart 8.3.2) at the onset of the crisis. The capital adequacy of banks also would have been higher, most likely giving more resilience to the banking sector (Chart 8.3.3) (we note that the policy is retained for three years after the systemic risk indicator drops below its critical level). Note, however, that we do not give any offset for a possibly beneficial mitigation of the effect of the crisis on credit rationing and uncertainty relative to what actually occurred, which might have had a favourable effect on output. Hence, the effect of the policy is largely negative on output (Chart 8.3.4) reflecting lower consumption and investment (Charts 8.3.5 and 8.3.6), while current balances are markedly higher over the crisis period (Chart 8.3.8).

Lending wedges would have been boosted by the policies, thus somewhat dampening borrowing. Corporate lending would have been much lower as compared to the baseline case, which would have been favourable for financial stability (Chart 8.3.11). Lower levels of corporate lending would have lowered banking sector assets (Charts 8.3.12 and 8.3.13) - over 3 per cent lower in the UK at the onset of the crisis in 2007 Q3 and around 7% lower in Italy. Finally, a marked reduction in a

[15] The UK policies are operative from 2004-9 while those in Italy work from 2004-6 and 2009–11, triggered by the systemic risk indicator.

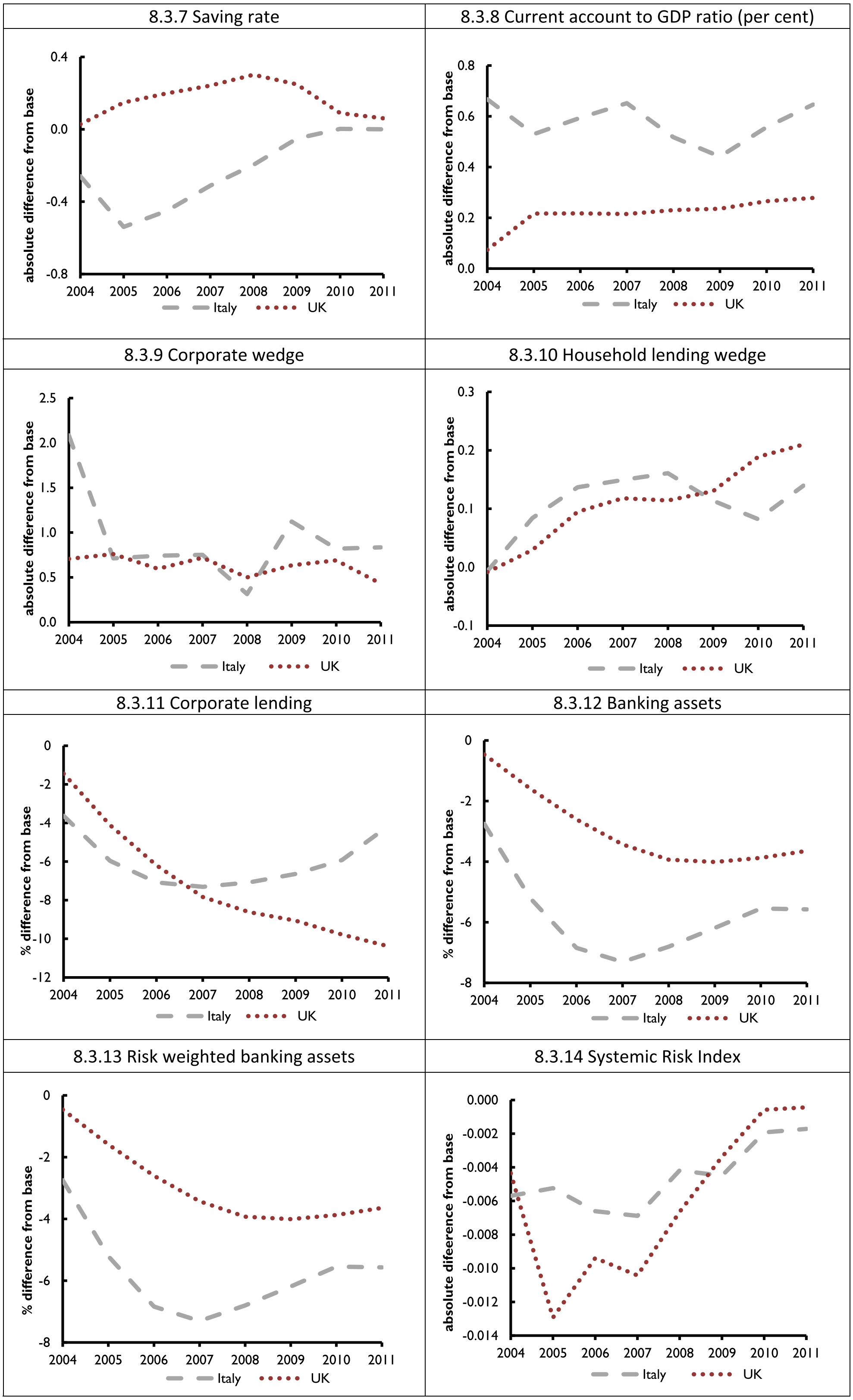

Chart 8.3. (*continued*).

systemic risk index suggests that the macroprudential policies would have reduced the possibility of the crisis occurring, or at least making it less severe (see the cost-benefit calculations in section 9) – again note the scale differs from the charts of *sri* in the earlier simulations.

9. Cost-benefit analysis

As noted above, and discussed further in Barrell et al. (2009), changing macroprudential policies change the probability of financial crises, and crises have clear costs for the economy. Hence, we can

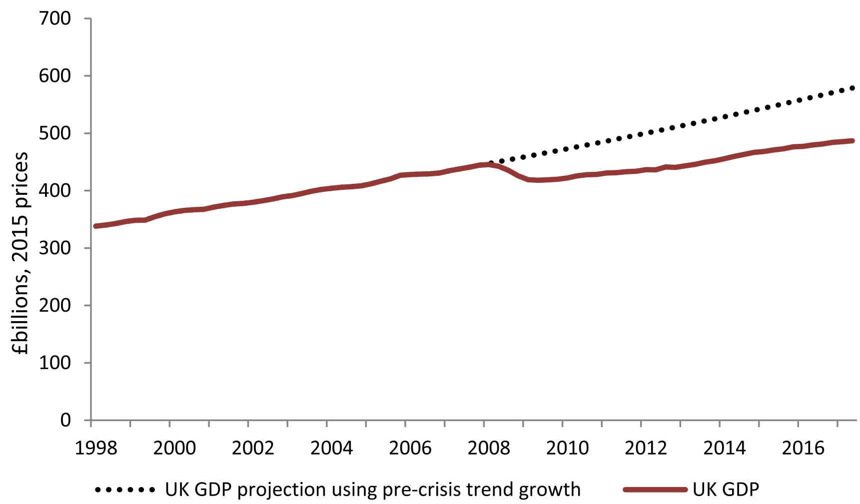

Chart 9.1. UK GDP and pre-crisis trend.
Source: NiGEM database and authors' calculations

calculate the expected gross gain from macroprudential policy implementation, and we can compare it to the gross costs in terms of output. If we were to take the net present value (NPV) of all costs and benefits from tighter macroprudential policies, we would have to take account of the costs incurred during a post-crisis recession. This would require us to analyse the effects of changes in macroprudential policies on the path of GDP.

The short-term costs of a crisis may be significant, and they are likely to be negative and could outweigh any other costs. The flow costs of the crisis may be written as the difference between our expectation of what output would have been at time t if there had been no crisis, versus the output if there was a crisis, and to obtain the policy benefits this is multiplied by the change in probability of the crisis owing to the policy action (lowering loan-to-value ratios or raising capital adequacy). Note that we assume that not only were there output costs resulting from the crisis, but also a slowing of trend growth, as shown in Chart 9.1 below. We use estimates of the cost of the subprime crisis in the UK as a simple comparison of the actual path of GDP with what GDP would have been if growth had persisted at its average rate over the 10 years prior to the crisis, to provide a baseline for costs. The pattern is shown in Chart 9.1 below.

Meanwhile, we can trace the effect of the macroprudential measures on the economy as set out above in a simulation with an application of macroprudential policies with no specific boom or bust (as in the GDP charts). We can also assess the impact of loan-to-value policy and capital adequacy policy alone. We can then calculate the net present discounted value of the benefit-cost difference by subtracting the cost from the benefit and discounting. In line with Barrell et al. (2009), we use a discount factor of 3 per cent.

A key question is then the way to calculate benefits. Absolute changes in probability may not be realistic, bearing in mind that the average across the sample of Barrell et al. (2010b) it is 0.0555 and for Karim et al. (2013) it is 0.0357, while our chosen critical levels are 0.05 for Germany, 0.03 for Italy and 0.01 for the UK. Accordingly, besides calculating the benefit using changes in absolute probabilities of crises, we recalculated the present value based on the relevant critical level (using as a measure of benefit the proportion of the critical level accounted for by the change in the systemic risk index due to the policy) and twice the critical level.

Note that we include in the results shown in Table 4 a combined simulation of both policies which is not included in the current article, since the model is largely linear the results are broadly equivalent to the sum of simulations 1 and 2 (charts for the combined simulation are shown in Carreras et al., 2018b). The results in Table 4 illustrate that use of absolute probabilities always results in a negative net present value (NPV), reflecting the low level of the *sri* over the crisis period (continuing the level shown in Chart 7.5) which means the NPV of gains (Charts 8.1.14 and 8.2.14) is insufficient to offset the costs to the economy (Chart 8.1.4 and 8.2.4). For the UK and Germany, benefits are substantially positive at the critical level of crisis probability and at double that level, while for Italy the net benefits are still negative. In each case, the capital adequacy policy has a greater cumulative net effect on GDP than the loan-to-value policy. This reflects two factors: First there is a greater impact on the systemic risk index from the capital adequacy policy than loan-to-value owing to the coefficients in the *sri* function which is larger for capital than for house prices. Second there is a greater absolute change in the risk adjusted capital ratio in the case of the capital adequacy policy. The negative effect in Italy relates to the low base level of *sri* in Italy which means that the benefit owing to the policy is very small over the simulation base. An additional factor is that, as is apparent from the simulations, the negative impact of capital adequacy policy on the Italian economy is greater than in the UK and Germany, which boosts the costs.

Finally for the historic simulation we show the NPV of the absolute gain from 2004 to 2016 from implementing the macroprudential policies as shown above, which for the UK is 4.3 per cent of GDP while it is −1.4 per cent for Italy. We attribute these differences largely to the differing crisis probabilities, notably in the run-up to the crisis, which were in turn reflected in the actual incidence of the crisis. The UK had scope for considerable benefits from application of macroprudential policies (Chart 8.3.14), which more than offset the costs. In contrast, benefits for Italy were relatively small. These were in turn reflected in actual outcomes where the crisis effect on the UK was considerable and that on the Italy was marginal. Again, the larger impact of macroprudential policy on GDP in Italy boosts the costs.

10. Conclusions

Against a background of growing use of macroprudential tools and the need for evaluation of their effects, it remains the case that as suggested by Galati and Moessner (2014, p2), “analysis is still needed about the appropriate macroprudential tools, their transmission mechanism and their effects”. Theoretical models are in their infancy and empirical evidence on the effects of macroprudential tools is still scarce. Theoretical models can highlight the transmission mechanism of real and financial factors and model calibrations can help with understanding how macroprudential regulation can reduce the risk of crisis. However, they often omit feedback from the macroeconomy to the financial sector, in particular a macroprudential reaction function. Additionally, they are

Table 4
Cost benefit calculations (monetary policy reaction function off, per cent of 2016 GDP, based on 7-year projection).

SRI change over 2017-23	Tightening of loan-to-value policy	Tightening of the risk-adjusted capital adequacy target	Combined simulation	Memo: Historic simulation over 2004-16
UK				
Absolute probability	−0.5	−0.9	−1.3	4.3
Crisis probability of 0.01	0.8	11.5	11.6	
Crisis probability of 0.02	0.2	5.2	5.1	
Germany				
Absolute probability	−0.6	−1.4	−2.1	0.3
Crisis probability of 0.05	0.7	9.9	9.7	
Crisis probability of 0.10	0.0	4.0	3.5	
Italy				
Absolute probability	−0.3	−4.5	−4.9	−1.4
Crisis probability of 0.03	−0.3	−3.9	−4.3	
Crisis probability of 0.06	−0.3	−4.2	−4.6	

often calibrated rather than estimated and/or would find disequilibrium hard to manage. Meanwhile, extant empirical work is typically focused on macroprudential policy's effect on a single variable such as credit or house prices. Hence, we contend that for practical policy purposes in macroprudential policy – such as comparing effects of alternative macroprudential policies – a semi-structural global macroeconomic model such as NiGEM is both more flexible and versatile and potentially more accurate than existing theoretical tools, while it enables us to capture economy wide effects that are by nature absent from single-equation empirical work.

Accordingly, using NiGEM, we provide estimates of the impact of two key macroprudential policy instruments on the wider economy for three major EU countries with contrasting financial histories and financial structures, namely the UK, Germany and Italy. We also assess the possible effect of introducing such tools prior to the subprime crisis, and evaluate the net benefits of macroprudential policies for GDP. In that case, the benefit is captured by the diminished probability of a crisis and the cost by the impact of macroprudential policies on output.

To obtain our results, we develop specific extensions to the global econometric model, NiGEM for a macroprudential block, as well as a systemic risk function that triggers endogenous introduction of macroprudential policies. As background, we outline the existing banking sector models for the countries concerned (see also Davis and Liadze, 2012). We then perform counterfactual scenarios based on the macroprudential block for policy tightening in respect of loan-to-value and capital adequacy policies, both in the future and over a historic period beginning in 2004. A data list is provided in Appendix 1, the source is the NiGEM database.

Among the key results are that we find the loan-to-value simulation impacts largely on consumption and the housing market, whereas the capital adequacy simulation has a greater effect on investment and overall output. Both simulations raise bank capital ratios and lead to a decline in bank lending. The impact on crisis probabilities of the loan-to-value simulation arises mainly from lower house prices (albeit also leading to higher bank capital ratios) while the capital adequacy simulation raises bank capital adequacy directly. Both also entail an improving current account balance (as the economy slows), and a rise in bank liquidity ratios (not illustrated in the charts). We find that generally, loan-to-value policy has a lesser effect than capital adequacy on crisis probabilities and net benefits. There are cross country contrasts, due to differences in financial and economic structure as reflected both in the data and results of estimation within the model, with, for example, both policies having a greater relative effect on *sri* in Germany than in the UK and Italy. Accordingly, the simulations show that authorities need to consider carefully not only the source of the concern for financial stability but also the financial structure and transmission mechanisms of the economy.

Meanwhile, the introduction of macroprudential policy prior to the crisis would have led to improvement in a number of key macroeconomic measures and might thus have reduced the incidence of the crisis. On the other hand, we do not give any offset for a possibly beneficial mitigation of the effect of the crisis on credit rationing and uncertainty relative to what actually occurred, which might have had a favourable effect on output. Hence the effect of the policy from 2004 is largely negative on output. Finally, across all simulations using imposed crisis probabilities based on sample averages, there are positive net benefits to macroprudential policy in Germany and the UK, but not in Italy.

Concerning limitations of our work, we note that macroprudential policy is more likely to be implemented in a discretionary manner, rather than being triggered by systemic risk as in the model. This is particularly the case given current low levels of the latter, which in turn reflect Basel III improvements to capital adequacy. The systemic risk function is of course largely focused on banking sector risk and resilience, and accordingly the model does not forecast as it stands the types of crisis that have originated in the non-bank sector such as the 1998 Russian financial crisis or the recent European sovereign debt crisis. Consequently, an assessment of non-bank imbalances may be a further area for research.

Further research might also focus on incorporation of additional macroprudential tools such as the debt-to-income ratio for mortgages as well as taxes on financial institutions, both of which were shown to be effective in Carreras et al. (2016, 2018a). A further important issue is to implement feedback from the real economy to bank capital adequacy and lending in the form of mortgage arrears for households and insolvencies for companies. Relevant equations were estimated in Davis and Liadze (2012) for these quantities. We can also assess the impact of macroprudential policy when monetary and fiscal policy do not partly offset their impact, i.e. varying the policy mix, as is illustrated in Carreras et al. (2018b), although effects of this in NiGEM are quite small. The cross-border feedback effects of macroprudential policy and domestic versus foreign factors affecting crisis vulnerability can also be assessed in NiGEM, given its versatility. These would arise mainly through competitiveness and trade as there are no explicit cross border capital flows, only gross assets and liabilities of each country that are subject to general revaluation. Finally, cost benefit analyses could be further extended to allow for implications of policies for the volatility of output.

Appendix 1. Data list

Variable names	Definitions
ARR	Rate of household mortgage arrears
BBAL	Banking sector assets (total)
BBSOA	Banking sector other assets
BCAP	Banking sector capital
BRA	Banking sector liquid assets
BRWA	Risk-weighted banking assets
C	Consumption
CBR	Current account to GDP ratio
CC	Consumer credit held by households
CCRATE	Household unsecured borrowing rate
CED	Consumer expenditure deflator
CORPL	Non-financial corporate debt
CORPW	Non-financial corporate sector lending wedge
HW	Value of personal sector housing stock (FOF)
INSOLR	Rate of company liquidations
IPREM	Investment premium
KH	Capital stock (housing)
LENDW	Rate Spread - household (borrowing - lending)
LEVRR	Risk-weighted capital to asset ratio
LEVRRT	Risk-weighted capital to asset ratio target
LIABS	Household liabilities (total)
LRR	Long real rates
LTV	Loan-to-value ratio
MORTH	Mortgage debt of households
NW	Net wealth, personal sector
NWPI	Net wealth to personal income ratio
PH	House prices
R3M	3 month interest rates
RHPG	Change in real house prices
RMORT	Average offered mortgage rate
RPDI	Real personal disposable income
SRI	Systemic risk index
Y	Real gross domestic product
YCAP	Trend output for capacity utilisation

Source: NIGEM database.

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